Science In Fire Fighting

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In

Fire-Fighting

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INTRODUCTION

The purpose of this work is to furnish the student fireman with a text-book in which the character and arrangement of the subject matter shall be such as to fulfill the following requirements:

(1) Provide a course of study adopted to the development of ability to engage in work requiring, in its performance, sound logical reasoning and sustained mental effort.

(2) Show the scientific principles involved in the various operations which firemen perform, and connect these principles with the performance, in such manner, that men acquainted with them may be capable of the maximum of efficiency in executing these operations.

(3) Furnish a large number of simple mathematical problems upon matters incident to operations performed at fires, including a number upon those features of hydraulics that are peculiarly applicable to fire service.

The work is arranged under three headings.

(1) Mechanics.
(2) Hydraulics.
(3) Heat and Combustion.

Under the heading of mechanics the scientific principles involved in handling appliances, raising and extending ladders and water-towers are shown, and the forces required in the execution of the various operations are shown mathematically.

The part that treats of hydraulics deals almost exclusively with the loss of power (represented by pressure), due to friction where water is forced

through hose lines, the carrying distance of streams, and discussion of the principles involved in those operations.

The principal object it is sought to accomplish, in that part of the work wherein heat and combustion are discussed, is to show how scientific knowledge acquired from a study of combustion, radiation, and heat diffusion in connection with industrial enterprises is applicable to conditions under which firemen encounter those forces.

Every statement made in the work bears directly upon the duties which firemen perform in effecting entrance into structures wherein there may be an outbreak of fire, or in combating such an outbreak, thus insuring that the mind of the student will be continually upon the subject of his duties while pursuing his studies. But while this has been the primary consideration, the subject matter has been selected and arranged to furnish the largest amount of liberal mental training possible within a space so limited.

The work may be regarded as an introduction into those avenues of science along which the studies of firemen should be directed rather than a complete treatment of any of those subjects.

Through the whole of the work the author has been guided by what appears to be the objects aimed at by the curriculums of our Military and Naval Academies, for the professional skill, executive ability, and splendid morale of whose graduates we have long entertained the most profound admiration.

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PREFACE TO PART I

Part 1 treats of those physical laws involved in the operations which firemen perform in connection with their work of extinguishing fires.

The greater portion of the laws that today may be applied to this work come naturally under that portion of the laws of "Motion and Force" included within the domain of Mechanics.

For this reason the subject matter is treated under the heading of Mechanics although some of the questions considered do not come within the scope of a strict application of the term.

It should scarcely be necessary to dwell upon the advantages that might reasonably be hoped to result, to men engaged in a line of work and to the community they serve, from having these men, or at least those who direct and supervise their operations, conversant with the principles involved in operations incident to their calling. It is true that there is an all too common belief that where the task to be performed necessitates the application of muscular force men easily learn from experience, or use, the most effective manner of applying that force. There may be some foundation in fact for this belief where the muscular force is applied directly to the body upon which it is intended to act, but it is an utter fallacy in so far as it is intended to apply to circumstances wherein the force is transmitted through one or more implements. That the belief is entertained is due to lack of or limited experience or observation in connection with the subject.

Anyone familiar with the principles involved in the use of levers cannot avoid doubting the value of experience as a teacher, on subjects demanding the application of force, after frequently observing firemen operate upon steel lined, steel bolted doors. The insufficiency of experience alone, as a teacher of this subject, comes with convincing vigor when it is learned that officers after serving for many years in sections of cities in which such doors are common have no well defined methods of attacking them.

(In the interest of officers serving in cities or parts of cities in which the type of doors and door fasteners here considered are not common it may be said, that such doors and door fasteners are the development of the past 10 or 15 years and that they are found almost exclusively in multi-tenanted commercial buildings. So difficult is it to force some of these doors that new methods or new appliances are in serious demand.)

In connection with the raising of ground rest ladders it seems, apart from any consideration of superior efficiency, a matter of simple justice that, when men are called upon to perform a task demanding in its execution the exercise of their utmost effort, that the man at whose behest the work is to be performed should know the force that must be applied in order that the operation he directs be accomplished.

In swinging extension ladders, and lowering them on a line at right-angles to the frame of the truck, persons unfamiliar with the mechanical principles involved are, for want of exact knowledge, incapable of utilizing such appliances to the full

limit to which it could safely be done by those fully conversant with these principles.

The force of reaction due to the discharge of streams, coupled with the principles of leverage involved wherever a stream from a water-tower is operated, seems an almost essential part of the education of chief officers who order water-towers into operation under the varying conditions that prevail at fires. Nor is it demanding too much to require that officers who send men up ladders to operate streams therefrom should understand the principles of reaction, stability, and of leverage involved in the operation. Unless they understand these principles there is no assurance that men operating lines from ladders are not exposed to unnecesary dangers. In relation to the operation of streams from ladders it may be said that even though men unfamiliar with these principles of reaction, stability, and leverage realize that there is danger they are frequently incapable of providing a reasonable factor of safety without unduly sacrificing efficiency. The primary reason, however, for advocating a study of principles just referred to lies in the fact that men unfamiliar with them do not realize that there is danger in operating lines from ladders.

The reaction resulting from the discharge of streams is a force which firemen have to contend with at every working fire, and it is only elementary fairness, to the community as well as to the firemen themselves, that they should be fully instructed in the principles applicable and on the manner in which those reactions may most conveniently be obviated.

Not only would a knowledge of mechanical principles enable firemen to operate appliances more effectively, but familiarity with those principles on the part of firemen generally should prove a very important factor in aiding departments in securing more suitable appliances and equipment. For the keen appreciation of a department's needs, that would develop amongst men possessed of such knowledge, would prove a valuable assistance in directing along sane and progressive lines the design of apparatus and appliances. In addition, the fact that the officers of a department were versed in mechanics, would stimulate care on the part of manufacturers in the construction of fire fighting equipment. It is especially to be desired that persons whose approval is necessary to the acceptance of apparatus be familiar with the principles of mechanics.

SCIENCE IN FIRE FIGHTING

Science is Distinguished from General Information in that in the former Knowledge is Classified and Systematically Arranged while in the Latter it is not.

MECHANICS

Mechanics is a Branch of Science which Treats of Forces and their Effects.

In order that we may be able to apply mechanical principles to the work of fire fighting, it is essential that we first familiarize ourselves with the fundamentals of that science, as well as the elements of the natural laws of: Motion, Velocity, Acceleration, Momentum, and Gravitation.

MOTION.—Motion is change of position.

If any point in a mass moves along a straight line that mass has motion of translation. While if any point in a mass describes a circle about another point in the same mass as a center that mass has motion of rotation.

VELOCITY.—Velocity is rate of motion, and its magnitude is expressed by saying that it is a stated distance in a given time, as 100 ft. per second, or 100 miles per hour.

Velocity may be uniform or variable.

The velocity of a body at any instant is the distance it would pass over in the next unit of time

if uninfluenced by external forces. Thus the velocity of a freely falling body at the end of the third second of its fall is the distance it would pass over in the fourth second if a counter force were applied that would exactly compensate for the attraction of the earth.

ACCELERATION.—Acceleration is change of velocity or of rate of motion. The rate of motion is said to be accelerated (+ or —) according to whether velocity is increasing or diminishing. The expression accelerated negatively is used in the sense of retarded, and the expression is used on account of its ready application in mathematical formula.

Where velocity is uniformly accelerated or retarded the acceleration is said to be constant.

If a body pass over a unit of space in a unit of time it has unit velocity. The velocity per second multiplied by the number of seconds measures the distance traversed in any given time by a body moving with uniform velocity. Representing these functions with h for height, or distance, v for velocity per second, and t for time counted in seconds, we have $h = vt$.

From this fundamental formula we derive algebraically the following:

$$v = \frac{h}{t} \text{ and } t = \frac{h}{v}$$

Wherever two of these values are known, they may be substituted in one of these formulas, and the third value obtained.

The formula just shown is the same as:

$$\text{If } a = bc \text{ then } b = \frac{a}{c} \text{ and } c = \frac{a}{b}$$

This may be shown in numerical form by:

$$\text{If } 8 = 2 \times 4 \text{ then } 2 = \frac{8}{4} \text{ and } 4 = \frac{8}{2}$$

Two of the values being known: If a body moves at a rate of 50 ft. per second for 10 seconds, and the distance traversed is desired, the first formula is applicable:

$h = vt$; $h = 50 \times 10 = 500$, the number of feet traversed.

If a body moving with uniform velocity has a change of position of 600 ft. in 12 seconds, the second formula applies:

$v = \frac{h}{t}$; becomes $v = \frac{600}{12} = 50$, the velocity in feet per second.

If the change of position and the velocity be known and the time is sought:

$t = \frac{h}{v} = \frac{600}{50} = 12$, time in seconds body was in motion.

Always bear in mind that where one number is written above another division is indicated.

LAWS OF FALLING BODIES.—Moving bodies are acted upon by the force of gravity. The motion of a falling body is accelerated by the force of gravity. As the force is constantly exerted, the velocity

constantly increases as the body falls, and the following has been found to be true: If a body starts from a state of rest, it will fall about sixteen feet in the first second of time, forty-eight during the second second, eighty feet during the third, and so on.

The distance that a body will fall during an interval of time may be shown as follows:

1st Second	2nd Second	3rd Second	4th Second
16	16	16	16
1	3	5	7
16 ft.	48 ft.	80 ft.	112 ft.

The total distance the body falls in four seconds is the sum of these products, which is two hundred and fifty-six feet; or according to a principle of multiplication, sixteen feet multiplied by the sum of the multiples $(1 + 3 + 5 + 7 = 16)$ $16 \times 16 = 256$ ft. The total distance may also be found by multiplying sixteen feet by the square of the number of seconds the body has been falling: 16 ft. $\times 4^2 =$ 256 ft.

This latter statement is true no matter how long a body may be falling, for at the end of two seconds the freely falling body has traversed:

16×2^2 or 64 ft. and at the end of 50 seconds it has traversed a distance of 16×50^2 or 40,000 ft.

The velocity at the end of the first second is at the rate of thirty-two feet per second. At the end of the second second, the motion has been accelerated to a velocity of sixty-four feet per second, and at the end of the third second to ninety-six feet per second. We see, then, that the velocity at the end of any second can be found by multiplying thirty-two by the number of seconds the body has been falling.

It is suggested that the student get as clear an understanding of acceleration as possible from the very elementary statement of the principles presented here. An application of these principles is essential in computing the carrying distance of streams, in connection with which subject acceleration is treated more extensively, and where what is mastered at this point may prove advantageous.

LAWS OF ACCELERATED MOTION.—The laws governing the motion of bodies starting from rest and gaining uniformly accelerated motion, may thus be stated:

(1) THE VELOCITY AT THE END OF ANY UNIT OF TIME EQUALS THE ACCELERATION MULTIPLIED BY THE NUMBER OF TIME UNITS.

(2) ACCELERATION EQUALS TWICE THE DISTANCE TRAVERSED IN THE FIRST UNIT OF TIME.

(3) THE DISTANCE TRAVERSED IN ANY SINGLE UNIT OF TIME EQUALS HALF THE ACCELERATION MULTIPLIED BY THE NUMBER OF TIME UNITS — 1.

(4) THE TOTAL DISTANCE TRAVERSED IN ANY GIVEN TIME EQUALS HALF THE ACCELERATION MULTIPLIED BY THE SQUARE OF THE NUMBER OF TIME UNITS.

MOMENTUM. — Motion produces momentum, therefore, any body in motion has momentum. The quantity of momentum depends on the mass (weight) and the velocity, and is the product of the mass multiplied by the velocity. If m represents the mass of a body and v its velocity, the product,

mv, will represent the quantity of the motion. This product, mv, is called momentum.

The momentum of a body having a weight of 20 lbs. and a velocity of 10 ft. per unit of time, is equal to the momentum of a body having a weight of 10 lbs. and a velocity of 20 ft., and is twice as great as that of a body having a weight of 5 lbs. and a velocity of 20 ft.

EXAMPLE.—A 10-pound ball moving at a velocity of 100 ft. per second. What was its momentum? In this case mv $= 10 \times 100$ or 1,000.

LAWS OF MOTION.—It should aid the student with some of the difficulties that will be encountered later, to remember and understand Newton's Laws of Motion, which are:

(1) EVERY BODY CONTINUES IN A STATE OF REST OR OF UNIFORM MOTION IN A STRAIGHT LINE UNLESS COMPELLED TO CHANGE THAT STATE BY AN EXTERNAL FORCE.

(2) EVERY CHANGE OF MOTION IS IN THE DIRECTION OF THE FORCE IMPRESSED AND PROPORTIONATE TO IT. (In this case motion means momentum and it is not necessary in support of the truth of the law that there should be a change in the direction of the course in which the body is moving.)

(3) ACTION AND REACTION ARE EQUAL AND IN OPPOSITE DIRECTION.

RESULTANT AND EQUILIBRANT.—Motion may be produced by the joint action of two or more forces. The single force that will produce an effect

like that of the component forces acting together is called a resultant. The single force that, acting with the component forces, will keep the body at rest is called the equilibrant. The resultant and the equilibrant of any set of component forces are equal in magnitude, and opposite in direction.

The point of application, direction, and magnitude of each of the component forces being given, the direction and magnitude of the resultant force are found by a method known as the composition of forces.

COMPOSITION OF FORCES.—Under composition of forces there are several cases, those necessary for our purpose being:

(a) When the component forces act in the same direction and along the same line. The magnitude of the resultant is then the sum of the given forces. Example: Rowing a boat down-stream.

(b) When the component forces act in opposite directions and along the same line. The magnitude of the resultant is then the difference between the given forces.

(c) The resultant of two forces that act in the same direction along parallel lines has a magnitude equal to the sum of the magnitudes of the components, and its point of application divides the line joining the points of application of the components inversely as the magnitudes of said components.

(d) When two equal parallel forces act at different points on a body and in opposite directions, the arrangement constitutes what is called a couple. It produces rotary motion, and the components can have no resultant.

(e) When the component forces have a given point of application and act at an angle to each other, as when a boat is rowed across a stream, the resultant may be ascertained by the parallelogram of forces.

Where forces are applied in the direction of the arms of a V the motion of the body will be along a line making angles with the arms of the V that vary inversely with the magnitude of the force applied.

FIRST LAW OF MOTION.—The first law of motion results directly from inertia. That is from the property of matter by virtue of which it persists in a state of rest or of uniform motion unless some outside force changes that state. HENCE, FORCE MAY BE SAID TO BE THAT WHICH CHANGES OR TENDS TO CHANGE A BODY'S STATE OF REST OR MOTION.

THE SECOND LAW OF MOTION.—The second law of motion may be stated thus: A GIVEN FORCE WILL PRODUCE THE SAME EFFECT WHETHER THE BODY ON WHICH IT ACTS IS IN MOTION OR AT REST: AND WHETHER IT IS ACTED UPON BY THAT FORCE ALONE OR BY OTHERS AT THE SAME TIME.

The statement of this law causes some confusion, for the reason that what Newton meant by motion in his second law has never been made quite clear. If we regard motion, as there used, as meaning both momentum and inertia, we can see that any force applied tends to change either the one or the other.

THIRD LAW OF MOTION.—ACTION AND

REACTION ARE EQUAL AND IN OPPOSITE DIRECTIONS.

THIRD LAW OF MOTION.—The effect of the third law of motion may be shown by example. When an ivory ball is projected against the cushion of a billiard-table the reaction of the cushion causes the ball to rebound, while the direct action causes a temporary dent in the cushion. In springing from a boat the direct action of the muscular exertion is to set the boat adrift, while the reaction puts the passenger ashore.

CENTRIFUGAL FORCES.—Although no problem involving the application of the principles involved in the measurement of centrifugal forces is dealt with in this work, it is deemed well to state the elementary principles upon which they are based. For the reason that, as fire fighting developes into a science, these rules will grow ever more and more important.

The laws of centrifugal force are:

(1) THE FORCE VARIES DIRECTLY AS THE MASS.

(2) THE FORCE VARIES DIRECTLY AS THE SQUARE OF THE VELOCITY (radius being constant).

(3) THE FORCE VARIES INVERSELY AS THE RADIUS (velocity being constant).

GRAVITATION

GRAVITATION.—Every particle of matter in the universe has an attraction for every other particle. This attractive force is called gravitation. Gravitation is unaffected by the interposition of any substance. The velocity with which a brick falls towards the earth is not affected by the existence of a scaffold between it and the earth (until the scaffold is reached). During an eclipse of the sun the moon is between the earth and the sun. But at such time the sun and the earth attract each other with the same force that they do at other times.

Gravitation is independent of the kind of matter, but depends upon the quantity or mass, and upon the distance. Mass does not mean size but density rather, and near the surface of the earth is represented by weight.

LAW OF GRAVITATION.—The mutual attraction beteen two bodies varies directly as the product of their masses, and inversely as the square of the distance between their centers of mass. Example, doubling this product doubles the attraction; doubling the distance, quarters the attraction. Doubling both the product of the masses and the distance halves the attraction.

The attraction between two bodies is mutual. The earth draws a body falling towards it with a force that gives that body a certain momentum, the body draws the earth with equal force, that gives it equal momentum. The momentum is the mass multiplied by the velocity.

GRAVITY.—The particular phase of the law of

gravitation with which we will have to deal is the attraction beteen the earth and bodies upon or near its surface. This form of gravitation is generally called gravity. Its measure is weight. Its direction is vertical, i.e., in a direct line towards the center of the earth.

WEIGHT.—As the mass of the earth remains constant, doubling the mass of a body weighed doubles the product of the masses, and consequently doubles the weight. When we ascend from the surface of the earth, there is nothing to interfere with the working of the law of universal gravitation; but when we descend below the surface, we leave behind us particles of matter the attraction of which partly counterbalances that of the rest of the earth. The weight of a body at one point of the earth's surface differs from its weight at another point, because the earth is not a perfect sphere and its density is not uniform.

LAW OF WEIGHT.—Bodies weigh most at the surface of the earth. For bodies in the earth's crust, the weight varies as the distance from the center. For bodies above the earth's surface, the weight varies inversely as the square of the distance from the center.

CENTER OF MASS, OF BODIES RESTING ON THE SURFACE OF THE EARTH.—The principles involved in the questions discussed under this heading are of especial interest to firemen whose work is influenced by them in a variety of ways. Men directing the operations of water towers, aerial and other ladders should be familiar with these

principles, as should those who control the handling of hose streams where pipe holders of any kind are employed. But it is especially to be desired that those principles be fully comprehended by men directing large operations. For men familiar with them are better able to judge the stability of walls, towers, roof tanks, or of structures generally, than those who are not.

A body's center of mass is a point the distance of which from any plane is equal to the average distance of the whole mass from the same plane. The whole mass may be considered as concentrated there.

(a) Gravity tends to draw every particle of matter downward in a vertical line. This force may be regarded as many parallel forces each acting upon a separate particle of matter. Or it may be regarded as the resultant of all these forces acting upon a single point. This point is the center of gravity.

(b) When a body is acted on by any force, there is a series of reactions in the opposite direction, the resultant of which has its application at a point called the center of inertia.

(c) Any force acting on a body at its center of mass tends to produce a motion of translation in the direction of the force; but, if the force acts on the body at any other point, it and the reaction at the center of mass form a couple that tends to produce rotary motion of the body.

(d) In a freely falling body, no matter how irregular its form or how indescribable the curves made by any of its projecting parts (the line of direction) in which the center of mass moves is a vertical line.

TO FIND THE CENTER OF MASS.—In a body suspended from a point, the center of mass will be brought as low as possible, and will, therefore, lie in a vertical line drawn through the point of support. This fact affords a ready means of determining the point experimentally.

(a) Let any irregularly shaped body, as a block of stone, be suspended so as to move freely. If a plumb line be dropped from the point of suspension and the direction be marked, the center of mass will be in the line. If a new point of suspension, outside of the line already determined, be taken, the center of mass will lie in this line also. But to lie in both lines it must lie at their intersection.

(b) When a body is of uniform density and of regular shape, its center of mass and its center of figure, or volume, coincide.

CENTER OF MASS MAY BE OUTSIDE OF THE BODY.—In some bodies as a ring, a cask or a ladder, the center of mass may not lie in the matter of which the body is composed. But the point, wherever it is found, will have the same properties as if it lay in the mass of the body.

THE BASE.—The side upon which a body rests is called its base. If the body be supported on legs, as a Paradox pipe holder, the base is a figure formed by joining the points of support.

EQUILIBRIUM.—A body supported on a single point will rest in equilibrium when a vertical line passing through its center of mass (line of direction), also passes through the point of support. A body supported on a surface will rest in equilibrium

when the line of direction falls within the base. In general a body is in equilibrium when the resultant of all the forces acting on it is zero. The center of mass will be supported when it coincides with the point of support, or is in the same vertical line with it. When the center of mass is supported the whole body is supported and rests in a state of equilibrium.

(a) When the line of direction falls without the base, weight and reaction of support become forces that form a couple and overturn the body.

Bodies supported in a point or on a single straight line may be classified as:

(1) A body supported in such a way that, when slightly displaced from its position of equilibrium, it tends to return to that position, is said to be in stable equilibrium. Such a displacement raises the center of mass.

(2) A body supported in such a way that, when slightly displaced from its position of equilibrium, it tends to fall further away from the position is said to be in unstable equilibrium. Such a displacement lowers the center of mass.

(3) A body supported in such a way that, when displaced from its position of equilibrium, it tends neither to return to its former position nor to fall further from it, is said to be in neutral or indifferent equilibrium. Such a displacement neither raises nor lowers the center of mass.

STABILITY.—When the line of direction falls within the base, the body stands; when without the base the body falls over. The stability of a body is measured by the amount of work that must be done to overturn it. This amount may be increased by

enlarging the base, or by lowering the center of mass, or by both.

HOW A KNOWLEDGE OF THE RELATIONSHIP BETWEEN CENTER OF MASS, BASE, STABILITY, AND EQUILIBRIUM MAY AID IN FIRE FIGHTING.—An officer unfamiliar with the principles of science discussed under the titles set forth in this heading must possess rare good judgment to enable him to determine how long men may safely be allowed to operate within the falling reach of walls whose stability have been impaired, without unduly risking their safety or diminishing the efficiency of operations. No definite rule can be ascribed as to when forces should be withdrawn from such positions. Much depends on the class of structure, the age of the walls, the nature of the occupancy and other circumstances which mitigate or magnify the hazard. The following rule will always hold good, and should aid immensely: Irrespective of the height of a wall it will not topple over until it has, at some point, leaned out of the perpendicular a distance equal to the thickness of the wall, at its narrowest section. This is due to the fact that it is only after it has leaned this far over that the line of direction (center of mass) is outside a perpendicular to the base from the side of the base towards which the wall leans.

In case of walls of graduate thickness they may lean more than this, and still maintain their equilibrium; for the lower part of the wall being heavier, per unit of height, the center of mass is nearer to the ground than to the top of the wall, hence the wall will lean farther out of plumb before the line of direction passes beyond the perpendicular to the

base. This latter is true even though the wall be plumb on the side toward which it leans.

Old walls may crumble before they lean sufficiently far to carry the line of direction beyond the perpendicular to the base. But when this occurs, the material falls close to the base and does not gravely endanger those operating on the outside.

There is little danger of towers falling in any other way than by crumbling, as in order to topple over they have to lean a distance equal to the external diameter of the tower.

TANKS, FLAG POLES, ETC.—Such parts of structures as these generally have anchors, or other fastenings, which may hold them in position after they have leaned so far as to carry their centers of mass beyond the base; yet it is only reasonable prudence to keep persons beyond the falling reach of any heavy object, on a burning building, that leans to such an extent as to carry the line of direction outside a perpendicular to the base.

EQUILIBRIUM OF SHIPS, BOATS, BOAT HOUSES, ETC.—One of the perils which officers commanding operations at fires on water craft should guard against is that of capsizing. When a floating structure lists so far over that a line dropped from a point half way between the gunwales (sides of the ship or boat), on the upper flush deck (deck extending full length and width of vessel), would strike the surface of the water outside the shell of the vessel, such ship or boat is in danger of capsizing. Although where the center of mass is low in the ship she would still be safe, yet as the information which a fireman can obtain, relative to

the structural design, and the nature and disposition of the cargo, on craft to which he may be called to combat a fire is too limited and unreliable to justify him in allowing persons on board vessels listed farther than above stated.

STABILITY OF APPARATUS AND APPLIANCES.—The laws of stable equilibrium, or as it is called in mechanics, stability, have to be taken cognizance of (consciously or unconsciously) by fire officers in many of the evolutions which they direct.

(1) The speed with which apparatus can safely be driven, particularly in making turns, depends on their stability.

(2) The pressure at which an extended water tower can safely operate, when the stream is directed at right angles to the frame of the tower (which is nearly always the case), as well as the pressure that can safely be applied to lines operated from ladders, is dependent on stability in each case.

(3) The angle to which an extension ladder may safely be lowered, when the turn table has been swung 90 degrees from its regular position, as well as the proper angle at which ladders should be used, depends on the law of stability.

(4) The extent to which pipe holders are helpful, to men directing hose streams depends largely on this law. And in this connection, an excellent example of the importance of taking this law into account, may be observed in the utility of the "Paradox" pipe holder with its broad low base.

INFLUENCE OF HEIGHT UPON STABILITY.—Most men have observed, or have been in-

formed, that a high load is more easily upset than one carried at less elevation. From this an impression seems to have developed that, under all circumstances, the higher a body is placed the more easily it may be overturned. This is an error. A stationary body, of uniform density, resting on a level plane, and having all its sides perpendicular, is not more easily turned over because of its height, except that owing to its height a power may be applied more advantageously. It will be necessary to understand this in connection with the computation of the angles to which bed ladders of hook and ladder trucks can be safely lowered, the pressure that can be applied to lines operated from ground rest ladders, and the pressure that can safely be used on a water tower, when extended to its full height, and other questions of a similar character.

MACHINES

IN THIS WORK THE WORD MACHINE SIGNIFIES AN INSTRUMENT FOR CHANGING THE DIRECTION OR VELOCITY OF MOTION, OR FOR THE TRANSFER OF ENERGY.—Machines may be designed to convert rapid motion into slow motion as in the case of the door forcer, or to convert slow motion into rapid motion as in the contrivance for raising water towers, and the bed ladders of aerial trucks.

Although there is a great variety of mechanical contrivances for the conversion of motion or the transfer of energy there are few principles involved. The mechanical principles most frequently applied in fire fighting are those of the lever, and those of the inclined plane. To the latter class belong the wedge and the screw, while the combination of wheel and axle derive its efficiency from the principles of the former.

WEIGHT AND POWER.—The action of a machine involves two forces, the weight and the power. The power signifies the magnitude of the force that acts upon one part of the machine; the weight signifies the resistance which another part of the machine encounters. The mechanical problem here dealt with is to find the ratio between power and the weight, or in other words, to ascertain what resistance may be overcome by one part of a machine by the application of a stated force to another part.

LIMITATION OF MACHINES.—No machine can create or increase energy. In fact, no machine can convert or transfer energy without some waste,

otherwise perpetual motion would be feasible. The waste of energy thus sustained is due to friction, weight of the moving parts of the machine, and want of rigidity. It is common in dealing mathematically with the mechanics of solids to disregard these wastes.

LAWS GOVERNING MACHINES.—In their operation machines are subject to the principle that the work done by the power equals the work done by the weight. (This principle is called "the conservation of energy.")

(1) The power multiplied by its velocity equals the weight multiplied by its velocity.

(2) The power multiplied by the distance through which it moves equals the weight multiplied by the distance through which it moves.

FRICTION.—Friction is the resistance that a moving body meets from the surface on which it moves. This is true whether the moving body rolls or slides. It is partly due to the adhesion of the bodies, but more so to their roughness. When dealing with the mechanics of solids, it is said that friction is independent of the velocity of motion and of the area of contact. It depends on the nature of the two substances, their roughness, and the pressure upon them, and, for substances of the same nature, it varies directly as the pressure.

When we come to deal with the mechanics of liquids we will find that the friction which water encounters in flowing over the surface of solids depends upon the velocity of flow and the relation between the wetted surface, (i.e.) the circumference,

and the area of cross-section, and is not influenced by the pressure.

CO-EFFICIENT OF FRICTION.—The co-efficient of friction is the relation between the friction and the pressure. It is the quotient obtained by dividing the force necessary to keep a body in motion by the normal pressure which the body exerts when at rest.

THE LEVER.—A lever is an inflexible bar that may be freely moved about a fixed point called the fulcrum. Every lever is said to have two arms, called respectively the power arm and the weight arm. *The power arm is the perpendicular distance from the fulcrum to the line in which the power acts; the weight arm is the perpendicular distance from the fulcrum to the line in which the weight acts.* If the arms are not in the same straight line, the lever is called a bent lever.

There are three classes of levers, the classification depending on the relative positions of the fulcrum, the weight and the power.

(1) If the fulcrum is between the weight and the power (P. F. W.) the lever is of the first class. The simplest forms of a lever of the first class are the crowbar, balance beam and pinchers.

In fire department service the tools used in forcing doors, such as door forces and claw tools, are commonly used as levers of the first class. It is this principle that is also involved in the raising of water towers and the bed ladders of hook and ladder trucks.

(2) If the weight is between the power and the

fulcrum (P. W. F.) the lever is of the second class. A nut cracker is a lever of the second class.

The principle upon which this class of lever operates is applied in fire service when the forked end of the claw tool is inserted under an iron shutter, between a concrete and a wooden floor, or between floor or roof sheeting and the beams, between tin or tar roof covering and roof sheeting, and the other end raised, thus prying up the shutters or prying loose the flooring, etc. It is also applied where one end of a ladder is inserted under timbers or floors and the other end raised, as is done to release persons pinned under fallen floors, etc.

(3) Where the power is between the weight and the fulcrum (W. P. F.) we have a lever of the third class. There are few simple machines constructed after the manner of this class of lever; the most common are tweezers used by surgeons, sheep-shears and the fire-tongs, which spring open when released, and to which the power is applied by the hand of the operator and between the fulcrum and the weight. It is the principle involved in this class of lever that must be applied in computing the power necessary to raise ground rest ladders, and it is, therefore, a matter of practical importance to firemen. Where the butt of a ladder is held to the ground, by the men who butt it, is the point of the fulcrum, while the men raising the ladder represent the power. In the early part of the operation, or before the center of mass falls behind the raisers, the work may be said to be done on the law of levers of the second class.

RELATIVE EFFICIENCY OF DIFFERENT

CLASSES OF LEVERS.—The principal purpose of the lever is to move heavy weights small distances. This is accomplished by transferring rapid motion into slow motion. For the accomplishment of this purpose the lever of the second class is more efficient than those of either the first or the third class. The lever of the second class is more powerful than the lever of the first class for the reason that the length of the power arm of the latter is the length of the lever minus the length of the weight arm, while in the former the length of the power arm is the total length of the lever. The lever of the second class is more efficient in converting rapid motion into slow motion than the lever of the third class for the reason that in the latter the weight arm is of necessity longer than the power arm, while in the former it cannot be as long.

MECHANICAL ADVANTAGE OF THE LEVER.—A given power will support a weight as many times as great as itself as the power arm is times as long as the weight arm.

The ratio between the arms of the lever will be the same as the ratio between the velocities of the power and the weight, and the same as the ratio between the power and the weight. If the power arm is twice as long as the weight arm, the power will move twice as fast as the weight does.

The power multiplied by the power arm is equal to the weight multiplied by the weight arm.

If P represents power, W weight and A arm, the formula may be written:

$$P \times PA = W \times WA$$

or

$$P : W :: WA : PA$$

The rule that the power multiplied by the power arm is equal to the weight multiplied by the weight arm applies to all straight levers, and whenever the values of three of the factors in the formula P:W:: WA:PA are known, the value of the fourth may be found. As if P is 100 lbs., W 1,000 lbs. and WA 2 feet PA will be

100:1,000::2:? In which case PA equals 20 ft.

or $\dfrac{1{,}000 \times 2}{100} = 20$, the length of feet of the power arm.

TO COMPUTE THE POWER OF THE LEVER.—In order to compute the ratio of the power and the weight, or resistance, it is necessary to adopt a unit of weight and a unit of measure. Adopting the pound as the unit of weight and the inch as the unit of measure, we find that the force of the power in pounds multiplied by the length of the power arm in inches is equal to the force of the weight in pounds multiplied by the length of the weight arm in inches.

EXAMPLE.—The power arm of a lever is 20 inches. The weight arm is 10 inches. How long will the lever be if it is of the first class? How long if of the second class? How long if of the third class?

ANSWER.—If of the first class 30 inches, for in this case the power arm is on one side of the fulcrum and the weight arm on the other. If of the second class 20 inches, for the weight arm is computed as part of the power arm. To constitute a lever of the third class, the weight arm must be longer than the power arm.

(2) A bar 12 feet long is to be used as a lever, keeping the weight 3 feet from the fulcrum. This may represent a lever of either the first or second class. In the first case a power of 10 lbs. will support a weight of $\frac{9 \times 10}{3}$ or 30 lbs. In the second case a power of 10 lbs. will support $\frac{12 \times 10}{3}$ or 40 lbs.

(3) The length of a lever of the first class is 10 feet. The weight arm is 4 feet, and at its end there is a weight of 40 lbs., while half way between that weight and the fulcrum there is a weight of 1,000 lbs. What force at the other end will counterbalance both weights?

$$40 \times 4 = 160,\ 1{,}000 \times 2 = 2{,}000,\ 2{,}000 + 160 = 2{,}160,$$

$$\frac{2{,}160}{6} = 360 \text{ lbs. Ans.}$$

(4) A claw tool has a bar 36 inches long, and the heel of the tool is 8 inches in a straight line from the point of the hook. The hook of the tool is inserted between a door and jamb and a force of 250 lbs. applied to the forked end of the tool. What stress is applied to the door at the point of the hook? From the formula we know that: P:W::WA:PA, which may be altered to its equivalent: WA:PA::P:W.

We know that WA is 8 inches, PA 36 inches and P 250 lbs. Hence the formula may be written:

$$8:36::250:W \text{ or } W = \frac{36 \times 250}{8} = 1{,}125 \text{ lbs. Ans.}$$

If in the case just considered the power were applied 10 inches from the end of the power arm we would have 8:26::250:? Ans. 812½ lbs. This illustrates how important it is to apply the power near the end of the power arm.

(5) A door forcer having a bar 24 inches long has its blade inserted between a door and jamb to a depth of 2 inches. If a power of 200 lbs. be applied to the end of the bar, what stress will the blade exert on the door? WA:PA::P:W, 2:24::200:? Ans. 2,400 lbs. Great as the computed efficiency of the door forcer is shown to be, its actual efficiency is even greater. For the perpendicular distance from the fulcrum to the line in which the resistance acts is less than the distance from the fulcrum to the edge of the blade. In comparing the relative efficiency for forcing doors, of the door forcer and the claw tool, it must be remembered that the door forcer's effective range is much less than that of the claw tool.

(6) A ladder 30 ft. long is used on the inside of a building having a ceiling height of 12 ft. If the fulcrum be placed 5 feet from the weight end of the lever, how high can the weight be raised?

The ratio of the distance through which the power and weight are moved will be the same as the ratio of the length of the power arm and the length of the weight arm. Hence: The distance through which the weight is moved multiplied by the length of the power arm equals the distance through which the power moves multiplied by the length of the weight arm, therefore 25:5::12:? Ans. 2.4 ft.

(7) If the weight to be lifted were 1,000 lbs.,

what power should be applied to the end of the power arm?

PA:WA::W:?. 25:5::1,000:?. Ans. 200 lbs.

(8) What is the greatest height to which the weight could be lifted, under the conditions of the last two questions if the ladder were used as a lever of the second class? In this case the weight is 1,000 lbs., the power 200 lbs., and the power arm 30 ft., and it is sought to find the length of the weight arm. W:P::PA:WA may be written 1,000:200:: 30:? Ans. 6 ft. Hence, when a ladder 30 ft. long is used as a lever of the second class, a power of 200 lbs. applied to the end of the ladder will sustain a weight of 1,000 lbs. placed six feet from the opposite end. With a weight arm six feet long the formula PA: WA::Range of the power arm :?, may be written

30:6::12:? Ans. 2.4,

which shows that when compelled to operate within a limited range, as firemen so frequently are, the lever of the second class is no more efficient than a lever of the first class.

FORCING DOORS.—Except where some peculiarity in the location of a door renders it impracticable to thus proceed, the following method will be found more effective for forcing doors equipped with cross-bar devices, than any other that has been developed so far.

(1) Hold the door forcer with the long arm horizontally across the door about two inches above the location of the cross bar and drive in the blade of the tool as far as it will go, then haul on the end of the forcer distant from blade, until the long arm

is at right angles to the door. Insert the hook of the claw tool six inches lower down, holding the long arm of the latter tool in a true horizontal line. Now haul out on the long arm of the claw tool, exerting the power near the forked end of that instrument, when the bar of the claw tool is at an angle of about 60 degrees with the door, the hooked end of a 6-foot hook should be inserted at the top of the door close to the jamb from which the door swings. In this way the door may be held from 5 to 7 inches away from the jamb. The head of an axe may now be inserted between the edge of the door and the jamb, and the axe used to pound the door bar until the fastenings of the latter are broken away or the bar bent so as to clear the fastenings.

When the claw tool is used below the bar with which the door is secured, it does not interfere with operations of the axe-man in pounding the cross bar out of its fastenings.

In the case of narrow halls with return stairs the newel post may make it impracticable to use the claw tool below the cross bar of the door.

Wherever such a condition is encountered the door forcer should be used below the cross bar and the claw tool about a foot above the bar. When this method is employed the door should be pulled open to the full range of the hooked end of the claw tool, and the long end of the forcer employed to pry out the bottom of the door, then an axe can be used to pound out the door bar as in the former case.

COMPOUND LEVER.—The compound lever is a mechanical device of great power, but is, as at present constructed, too complicated for the condi-

tions under which firemen are compelled to operate. If some fireman, with a mechanical turn, could utilize the principle involved in this class of lever in a machine that could be conveniently carried and effectively used it would prove a great aid to firemen in the performance of the most difficult task with which they are now confronted.

RATIO OF THE POWER AND THE WEIGHT IN OPERATIONS WITH COMPOUND LEVER.—The ratio of the power and weight where the compound lever is employed. The continued product of the power and the lengths of the alternate arms, beginning with the power arm, equals the continued product of the weight and the lengths of the alternate arms, beginning with the weight arm. This statement may not be very illuminating, but there is no great difficulty in determining, from actual inspection, which are the power arms and which the weight.

WHEEL AND AXLE.—The wheel and axle consists of a wheel, or some substitute therefor, such as a crank handle, united to a cylinder in such manner that they may be turned together on a common axis. It is a modified lever of the first class.

Considered as a lever, the fulcrum is the common axis, while the arms of the lever are the radii of the wheel and of the axle.

MECHANICAL ADVANTAGE OF THE WHEEL AND AXLE.—The mechanical advantage to be derived from the use of the wheel and axle is equivalent to that derived from the use of a lever of the first class. And if the radius of the wheel

be denoted by R and that of the axle by R′ the formula

$$P:W::WA:PA \text{ becomes } P:W::R':R$$

The wheel and axle is extensively employed in fire department work as:

(1) In extending the fly ladders of hook and ladder trucks.

(2) In extending the inner tubes of water towers.

(3) In raising the bed ladders of hook and ladder trucks.

(4) In raising the masts of water towers.

APPLICATION OF THE LEVER PRINCIPLE THROUGH THE WHEEL AND AXLE.—The diameter of a wheel is 4 feet; that of the axle 6 inches; the weight to be raised is 1,000 lbs., and it is sought to determine the power that must be applied to the wheel in order to raise it.

The wheel having a diameter of 4 feet or 48 inches has a radius of 24 inches, while the radius of the axle is 3 inches. Hence, by substituting the known values, the formula P:W::R′:R becomes P:1,000::3:24, and

$$P = \frac{1{,}000 \times 3}{24}$$ or 125 lbs., the power that must be applied to the wheel.

WHEEL AND AXLE APPLIED TO FIRE DEPARTMENT WORK.—The fly ladder of a two-piece hook and ladder truck weighs 500 lbs. The diameter of the drum around which the extending cable passes is 6 inches, while the web of the crank handle is 12 inches. There is a crank handle on each side of the turn table. What weight will be sustained

by men holding the crank handles to hold the partly extended ladder in position?

$$P:W::R':R \text{ is } P:500::3:12$$

or $P = \dfrac{500\times3}{12}$ or 125, which, divided by 2, gives $62\frac{1}{2}$ lbs., the weight which each man sustains.

Men who in extending fly ladders find it necessary to tug at the crank handles may be somewhat surprised to learn that the work they are doing can be accomplished by the application of a power of $62\frac{1}{2}$ lbs. to each crank handle. There is great waste of energy in this class of work, especially where the fly is extended while the bed ladder is at a considerable angle from the vertical. This is due to the lever stress which the ladder imposes on the rollers. The farther out a fly ladder is extended the greater becomes the resistance which it encounters from this cause.

EXTENDING A THREE-PIECE LADDER.—In discussing the three-piece ladder the upper part will be referred to as the fly, and the middle part as the middle section.

The fly of an ordinary two-piece ladder is extended by a cable attached near the bottom of the fly, passed over a pulley attached to the top round of the bed ladder and wound on a drum attached to the bed ladder near its lower end.

The middle section of a three-piece ladder is extended in a manner similar to that of the fly in the two-piece ladder. The fly in the three-piece ladder is carried on two cables, which pass over pulleys on the upper end of the middle section of the ladder,

and are secured to the top of the bed ladder and near the bottom of the fly. By this contrivance the fly extends twice as rapidly as does the middle section and their maximum extension is reached simultaneously.

POWER NECESSARY TO EXTEND A THREE-PIECE LADDER.—The middle section of a three-piece ladder has a weight of 800 and the fly a weight of 400 lbs. The drum on which the hoisting cable is wound has a radius of three inches, while the webs of the crank handles are each 15 inches long. The gear on the crank shaft has 17 cogs, that on the drum shaft 34. What power applied on the crank handles will sustain the weight of both ladders? The only material difference between this and the problem immediately preceding is that here we have to consider the effect of the different sized gears. For the weight of the two ladders may be stated as one factor in the formula.

$P : W :: R' : R$ which may here be written:

$P : 1200 :: 3 : 15 \times 2$, for the gear on the drum shaft is twice as large as the one on the crank shaft.

$$P = \frac{1200 \times 3}{15 \times 2} \text{ or } P = \frac{3600}{30}$$

That is, the power applied to the crank handles that will sustain this weight is 120 lbs. or 60 lbs. on each crank handle. If this type of ladder is not well designed and carefully constructed, or if the cables supporting the fly are not kept at equal tension, and the movable parts well oiled there is likely to be considerable friction. In any case the power necessary to extend one of these ladders is considerably

more than that required to sustain them in position. But the ratio between the power necessary to sustain such a ladder and that necessary to extend it cannot be computed until coefficients of friction have been determined by carefully conducted experiments.

INNER TUBE OF A WATER TOWER.—The inner tube of a water tower consists of a steel tube thirty-six feet long, five inches internal diameter and five and seven-eighths inches external diameter. From the diameters stated it may be seen that the internal circumference of the pipe is 15.7 and the external circumference 18.5. Hence the metal in the pipe is equivalent to that in a flat plate 17 inches wide, 432 inches long and seven-sixteenths thick, which shows the mass of metal in the pipe to be 1.86 cubic feet, for $432 \times 17 = 7,344$.

$7,344 \times 7/16 = 3213$. That is, the mass of metal in the tube has a volume of 3213 cubic inches or

$$\frac{3213}{1728} = 1.86 \text{ cubic feet.}$$

Steel has a specific weight of 7.8. That is, any volume of steel weighs 7.8 times as much as an equal volume of water. Water weighs 62.4 lbs. per cubic foot. Hence, the weight of the tube under consideration is $1.86 \times 7.8 \times 62.4$ that is 9054 lbs. The fittings weigh about 150 lbs.

TO EXTEND THE INNER TUBE OF A WATER TOWER.—The inner tube of a water tower is extended by an application of the principles of the lever through the medium of the wheel and axle. The contrivance consists of two cables attached to a yoke, which is in turn secured to the in-

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ner tube near its lower end. These cables pass over pulleys placed in the outer frame or shell of the tower $4\frac{1}{2}$ feet from the top, and wind on a drum secured near the lower end of the outer shell. The drum shaft has a radius of 3 inches, is fitted, at each end, with a cogged gear having 68 teeth, in each gear. A crank shaft runs parallel to the drum shaft. This crank shaft has 15 toothed gears meshing into the gears of the drum shaft, and a 15-inch handle at each end.

The power necessary to apply to each crank handle in order to extend an inner tube, whose weights and dimensions are as stated, may be determined by working out the following formula:

$P:W::R':R$ in which the value of W is 1,100, that of R' 3, and that of R $15 \times 2 \times 4\frac{1}{2}$, the latter factor being the length and number of crank handles and the ratio of the gears. Hence the formula may be written: $P:1{,}100::3:35$, or $P = \dfrac{1100 \times 3}{135} = 25$ lbs. which represents the power that must be applied to each crank handle in order to sustain the weight of the tube.

EXTENDING THE TOWER WHEN THE TUBE IS FILLED WITH WATER.—When the tube is filled with water the value of W is 1100 + the weight of the water. The weight of the water may be determined by multiplying the volume of the pipe in cubic feet by 62.4, and the volume of the pipe may be found by multiplying the cross-sectional area of the pipe in square inches by the length of the pipe in inches and dividing the product by 1728, the number

of cubic inches in one cubic ft. The weight of the water equals

$$\frac{5^2 \times .7854 \times 432}{1728} \times 62.4 \text{ or } 307 \text{ lbs.}$$

As the tube is extended upwards an addition of 8 lbs. will have to be added for each foot it is advanced. When the tube is advanced to its full extent the weight added for water will be 500 lbs.

The value of W in the formula will be 1600 and the formula may be written:

$$P:1600::3:135 \text{ or } P = \frac{4800}{135} = 35.5$$

It may be observed that the ratio of the weight, to the power, allowed for hoisting the tubes of water towers, is much less than in the case of the fly ladders.

The greater ratio of power is deemed necessary in the case of water-towers, for the reason that towers have to be extended while streams are in operation.

At the present state of our knowledge on this subject, it is not practicable to compute the power necessary to overcome the resistance that the operation of a stream from a water-tower offers to the elevation of the inner tube. This resistance depends on the degree of perfection attained in fitting the bearings through which the tube passes, the efficiency of the lubricating medium employed and the completeness of the lubrication of the bearings and of the tube.

The most that appears practicable at the present time is to present a formula by which the resistance may be computed, when a coefficient of friction is evolved.

FORMULA FOR COMPUTING RESISTANCE DUE TO THE OPERATION OF A STREAM FROM A WATER-TOWER.—Multiply the pressure in pounds per square inch, under which the stream is discharged, by the area of the nozzle in square inches, and the product by the distance in inches from the top of the outer shell to the level of the nozzle. Divide this product by the distance in inches from the lower inner-tube guide to the top of outer shell. Multiply this quotient by the coefficient of friction, when the last product will represent the resistance which the operation of the stream imposes.

THE COEFFICIENT OF FRICTION CAUSED BY THE OPERATION OF THE STREAM BEING REPRESENTED BY ?.—The coefficient of friction being represented by ?, the formula employed in the question immediately preceding may be written:

$$P : W + A \times p \times \frac{d}{d'} \times ? :: 3 : 135,$$

in which A is the area of the nozzle in square inches, p the pressure in lbs. per square inch, d the distance from the top of the outer shell to the level of the nozzle and d′ the distance from the lower bearing to the top of the outer shell. If A represents 3 square inches, p 50 lbs. per square inch, d 20 ft. or 240 inches, and d′ 5 ft. or 60 inches, the formula may be written:

$$P : 1600 + 3 \times 50 \times \frac{d}{d'} \times ? :: 3 : 135$$

$$\text{or}\quad P = \frac{1600 \times 3 + (3 \times 50 \times 4 \times ?)}{135}$$

until the value of ? is determined by experiment, it would confuse the subject to carry the formula further.

Formula in which empirical coefficients are employed have little scientific value, but are used on account of their practical utility. In the case in question: A steel tube with smooth finish, snuggly fitted in brass bearings, with the whole well oiled should offer slight resistance, while if the tube and bearings be of steel or iron, and are allowed to rust, they may offer such resistance that it would prove impossible to extend the tube while the tower is in operation.

THE PULLEY.—The pulley is a lever of the first or second class. In the manner in which the forces are transmitted it differs from the wheel and axle, in that when it (the pulley) moves the attachments of the forces are moved. The mechanical advantage afforded by the pulley is due to the fact that the various parts of the cord extending from the stationary to the portable pulley sustain part of the weight.

FORMS OF PULLEYS.—Combinations of pulleys are made in great variety. In the most common forms a continuous cord passes around all the pulleys. The greater the number of sheaves mounted on a block the greater weight that can be sustained by a given power on the power end of the cord.

MECHANICAL ADVANTAGE OF THE PULLEY.—With the ordinary arrangement of pulleys, like that used in the block and tackle, the part

of the cord to which the power is applied carries only part of the load, the magnitude of that part varying inversely as the number of sections into which the movable pulley divides the load. With pulleys thus arranged, a given part will support a weight as many times as great as itself as there are parts of the cord supporting the movable block, and the distance a load is lifted equals the quotient obtained by dividing the distance moved by the power by the number of parts of the cord supporting the movable block.

The most ingenious application of the lever, through the medium of the pulley, is that employed in the differential pulley, which consists of an endless chain reeved upon a solid wheel that has two grooved rims and is carried in a fixed block above, and upon a pulley below. The two rims of the wheel in the upper block have different diameters, and carry projections to keep the chain from slipping on them. When the chain is pulled down until the upper wheel turns once upon its axis, the chain between the two pulleys is shortened by the difference between the circumferences of the two rims of the upper wheel, and the load is lifted one half that distance. By this device not only are long ropes rendered unnecessary, but the load remains suspended after the power end of the chain is released.

OTHER SIMPLE MACHINES

The mechanical devices other than the lever and the wheel and axle, classed as simple machines, are not extensively used in fire fighting proper, but possess an interest for firemen to the same extent,

as to others engaged in the execution of work involving the application of force. An understanding of the principles involved may lead towards a fuller comprehension of what has been stated, in relation to the lever and its modification, than would be otherwise likely to result.

INCLINED PLANE.—An inclined plane is a smooth, hard, inflexible surface, placed so as to form an oblique angle with the horizon.

A BODY RESTING ON AN INCLINED PLANE.—When a body is placed on an inclined plane, the gravity pull is resolved into component forces. One of these acts perpendicular to the plane, producing pressure upon it, the other tending to produce motion down the plane. To resist this latter tendency, and thus to hold the body in position, a force may be applied in one of three ways.

(1) In a direction parallel to the length of the plane.

(2) In a direction parallel to the base of the plane, i.e., horizontal.

(3) In a direction parallel to neither the length nor the base.

MECHANICAL ADVANTAGE OF THE INCLINED PLANE.—The mechanical advantage to be derived from the use of an inclined plane varies with the three conditions above given.

(1) When a given power acts parallel to an inclined plane, it will support a weight as many times as great as itself as the length of the plane is times as great as its vertical height.

(2) When a given power acts horizontally it will

support a weight as many times as great as itself as the horizontal base of the plane is times as great as its vertical height.

(3) Cannot be computed.

THE WEDGE.—A wedge is a triangular prism of hard material, fitted to be driven between objects that are to be separated, or into anything that is to be split. It is a union of two inclined planes united at their bases. As the power is generally applied by blows on the thick end, the effective force of which it is difficult to compute, no rule of the relation between power and weight can be given. It may be said, however, that for any given thickness, the longer the wedge the greater the mechanical advantage.

MECHANICAL PRINCIPLES APPLIED TO FIRE-FIGHTING.

COUNTERBALANCING ELONGATED BODIES.—Where a weight occurs in the form of a body of measurable length, the power necessary to sustain it is equal to that which would balance a body of equal weight, if the latter were placed at a point distant from the fulcrum equal to that of the center of mass of the elongated body, the center of mass being the point at which a body must be supported in order to balance. With straight levers of the second and third class this can be determined empirically or computed, while in case of levers of the first class it can be computed.

EXAMPLE.—(a) A metal bar, of uniform cross-section, 40 inches long and weighing 20 lbs., is

supported 2 inches from one end. What power applied at that end will balance the bar?

The bar on the weight side of the fulcrum is 38 inches in length, and has a weight of 19 lbs. Being 38 inches in length the center of mass is 19 inches from the fulcrum and the effective weight to be counter-balanced is 19 $\times$ 19, or 361. The weight of the bar on the power side of the fulcrum is one pound and its center of mass is one inch from the fulcrum, therefore its effective weight is one pound and the weight to be counter-balanced is 360 lbs. As the effective length of the power arm is 2 inches the weight necessary to balance the bar is $\frac{360}{2}$ or 180 lbs.

(b) When a fly ladder is down and the bed ladder is secured in a horizontal position, the bed and fly ladder have an effective weight of 25 lbs. to the running foot, equally distributed throughout their length, which length is 40 ft. from the center of the bearing shaft. The frame of the ladder extends 2 ft. on the other side of the bearing shaft. What power must the springs exert to elevate the bed ladder? The center of mass is 20 ft. from the bearing shaft, or fulcrum, and the weight is 25 $\times$ 40 or 1,000 lbs. The weight that will have to be overcome is represented in P:W::WA:PA or P:1,000::20:2. Ans. 10,000. The springs will have to exert a power of more than 10,000 lbs. in order to elevate the bed ladder.

(c) In a three-section ladder weighing 2,000 lbs. the distance from the end of the ladder to the bearing shaft is 36 ft. The opposite end of the bed lad-

der extends 2 ft. beyond the bearing shaft. Here the formula P:W::WA:PA becomes P:2,000::18:2. Ans. 18,000. Hence the power that must be applied to raise this ladder must be more than 18,000 lbs. As the traction motor of a truck is utilized to raise this class of ladder there is no nice question of power to be dealt with, except so far as relates to the transmission of the power. The difficulty with this type of apparatus is that the power necessary to overcome the great resistance, offered by the ascending ladder, has to be transmitted from a high speed motor to the slow moving raising mechanism. To provide a system of transmission of sufficient strength to ensure, at each and every point, an adequate factor of safety requires the application of nice engineering skill. It is doubtful if a system of cog-gears could be devised that would be reasonably safe, under the varying conditions of service, because of the fact that, in a cog-gear system, the entire weight must, of necessity, be supported on one tooth. The employment of worm gears or screws, in which an adequate factor of safety could be provided, seems impracticable on account of the impedence which the turn table interposes.

MANUAL POWER APPLIED TO THE RAISING OF BED LADDERS.—The manual raising devise of a bed ladder consists of two crank handles with 18 inch webs on a shaft equipped with two gears, each gear having 15 cogs. These gears mesh into 68 cogged gears on an idler shaft. From the idler shaft the power is transmitted by two 12 cogged gears to quadrants, the arms of which are 20 inches long, and constitute the power arm of the

ladder. The information just considered may be obtained by count and measurement, and by its application we may compute the power necessary to apply to the crank handles in order to raise the ladder, provided we know the length of the ladder and its center of gravity.

With a ladder extending 40 feet beyond the bearing shaft and weighing 1,000 lbs., the value of the various factors in the formula P:W::WA:PA are

$$W = 1{,}000 \text{ lbs.}$$
$$WA = 240 \text{ ins.}$$
$$PA = 18 \times 20 \times 4\tfrac{1}{2}$$

In which 18 is the length in inches of the crank handle, 20 the length in inches of the power arm, and 4½ the ratio of the gears on the crank and idler shafts.

Hence $$P:1{,}000::240:18 \times 4\tfrac{1}{2} \times 20,$$

or $$P = \frac{1{,}000 \times 240}{18 \times 4\frac{1}{2} \times 20} = \frac{240{,}000}{1{,}620} = 148$$

That is, a power of 74 lbs. on each crank handle would support the weight of the ladder.

Ladders equipped as described here have spring assists, and the great power ratio of the gears is to provide sufficient force to wind the springs to such tension that they will throw the ladders up.

As may be seen from a comparison of the gears on the crank and drum shafts it requires 22½ revolutions of the crank handles to erect the ladder. It requires more time to execute 22 revolutions of crank handles than can be allowed under fire fighting conditions.

WATER TOWERS.—Unlike the bed ladders on

hook and ladder trucks, the weight is not uniformly distributed in the masts of water towers. Hence before we can compute the power necessary to raise one of these masts to an elevated position it is first necessary to find its center of gravity. The weight is so distributed in the mast of a water tower that it is heaviest near the bearing shaft, which we shall call the fulcrum, and graduates uniformly towards the opposite end. If the weight per foot of the tower is not known it is necessary to measure the material of the mast frame and compute the taper of the bar that the material of the frame work makes. There is no especial principle of mathematics or mechanics involved in these measurements. The cross-sectional area of each end of the bar being known, the center of gravity may be found by the following rule.

RULE.—(a) To the area of the small end add one-third the difference between the area of the large end and that of the small. Multiply this sum by the length of the mast and divide the product by the sum of the cross-section area of the large and small end. The quotient obtained will be the distance from the fulcrum to the center of gravity of the bar. The cross-sectional measurements may be in square inches and the length of the mast computed in feet.

(b) Where the weight per foot is known the rule is substantially the same except that the graduation is stated in lbs. in lieu of in square inches.

RULE FOR FINDING THE CENTER OF GRAVITY OF WATER-TOWER MASTS.—Rule. —To the weight of the topmost foot of the mast add one-third the difference between that weight and the

weight of the foot nearest the fulcrum. Multiply this sum by the length of the mast and divide the product by the sum of the weight of the foot nearest the fulcrum and the foot most distant, the quotient obtained will be the distance from the fulcrum to the center of gravity of the mast, which, it will be remembered, represents the length of the weight arm.

EXAMPLE.—The mast of a water-tower extends 36 feet from the center of the bearing shaft; the weight of the foot nearest the fulcrum is 60 lbs., that of the foot most distant 40 lbs. The decrease in weight is uniform. In conformity to the rule $60 - 40 = 20$, $\frac{20}{3} = 6.7$, $40 + 6.7 = 46.7$, $46.7 \times 36 = 1{,}681.2$, $\frac{1{,}681.2}{100} = 16.8$. That is, the center of gravity in this case is 16.8 ft. from the fulcrum, or 1.2 ft. from the middle point measured by length. Hence the weight arm of the lever is 16.8 ft.

The weight being 60 lbs. per ft. at one end and 40 at the other, the average per foot is 50 lbs. Now $50 \times 36 = 1{,}800$, which, having its center of mass 16.8 ft. from the fulcrum, offers a resistance of $1{,}800 \times 16.8$ or 30,240 lbs. Now, if the frame of the tower extends 2.5 ft. on the power side of the bearing shaft the power necessary to raise the tower is $\frac{30{,}240}{2.5}$ or 12,096 lbs.

HYDRAULIC WATER-TOWERS.—When the

magnitude of the power necessary to overcome the resistance that is encountered in raising water towers is determined, the next step is to find the most convenient method by which this power can be furnished under the conditions prevailing.

(a) The available pressure being known it is sought to find the diameter of the smallest cylinder that will furnish the required power. If the resistance to be overcome is, as in the preceding example, 12,096, and the usual arrangement of two cylinders is to be provided, and a pressure of 100 lbs. to the square inch available, a power of 6,048 lbs. will have to be developed in each cylinder. The area of the smallest cylinder that will furnish the necessary power may be found by dividing the power that must be provided by the pressure available (the latter in pounds per square inch, the former in pounds). In this case the area of the cylinder necessary will be $\frac{6048}{100}$ or 60.48 square inches. The area being ascertained all that is necessary is to find the diameter, which is accomplished according to the well established mathematical formula which may be written thus: $D = \sqrt{A \div .7854}$, in which D is the diameter, A the area and .7854 the constant by which the square of the diameter is multiplied to find the area of a circle. In the present case the area being 60.48, the problem is $D = \sqrt{60.48 \div .7854}$. The square root 60.48 is 7.8 and the square root of .7854 is .885. Hence, the diameter of the cylinders should be at least $\frac{7.8}{.885}$ or 8.81 inches.

(b) Where the area of cylinders and the resistance to be overcome are known and it is sought to find the pressure that must be made available, divide the resistance that must be overcome by the combined area of the cylinders in square inches, and the quotient will be the pressure required. The total resistance being 12,096 lbs. and the diameter of each cylinder 8 inches, the pressure that must be available is $\frac{8 \times 8 \times 2 \times .7854}{12,096}$ or 120.3 lbs. That is, if the diameter of the cylinders were 8 inches, it would be necessary to provide for a pressure of at least 120.3 lbs. + that necessary to overcome friction. Where, as in the case of water-towers, no provision is made for hand raising devices, with which mechanical contrivance may be re-enforced, it is necessary to allow in addition to that computed, an excess power of 25 per cent to overcome friction and as a factor of safety.

THE SCREW.—A screw is a cylinder, generally of metal, with a thread around its circumference. The thread works in a nut within which there is a corresponding spiral groove cut to receive the thread. The screw is a modified form of inclined plane, as may be seen by inking a continuous thread, winding a sheet of paper about it, and cutting along the ink mark.

(a) The power is generally applied by a wheel or lever, moved through the circumference of a circle. The distance between the consecutive turns of any continuous thread is called the "pitch of the screw."

(b) The screw is much used where great resistance has to be overcome, as in propelling ships, compressing vegetable fibers during the process of baling, raising buildings, etc.

(c) Before the development of the spring raising devices the screw was applied to the raising of bed ladders on hook and ladder trucks. In ladders of that type, which we have had an opportunity of studying, the pitch of the screw was too great, making the power necessary to raise the ladder more than the four men, for whom space on the turn table was provided, could effectively furnish. The screw raised ladder was preeminently safe, but there is an inherent difficulty in adopting the screw to the raising of fire ladders.

MECHANICAL ADVANTAGE OF THE SCREW.—With the screw, a given power will support a weight as many times as great as itself as the circumference described by the power is times as great as the pitch of the screw.

APPLICATION OF THE PRINCIPLE OF THE SCREW TO THE RAISING OF BED LADDERS.—If the screw had a pitch of two inches and the crank webs were 18 inches long, the ladder 40 feet long, weighing 1,000 lbs., and having a power arm of 20 inches, the power necessary to sustain the weight is shown in the formula: $P:W::WA:PA$, in which W equals 1,000, the weight of the ladder in lbs., and in which WA equals $20 \times 12 \times 2$, the length of the weight arm in inches multiplied by the pitch of the screw in inches.

And the value of PA is $20 \times 36 \times 3.1416$, the length of the power arm in inches multiplied by the

circumference described by the crank handles in inches.

By substituting the values in the formula: P:W::WA:PA, we get: P:1,000::20 × 12 × 2:20 × 36 × 3.1416, or

$$P = \frac{1000 \times 480}{2262} = 212 \text{ lbs. Ans.}$$

Since there are two crank handles a weight of 106 lbs. would have to be applied to each, in order to support the weight of the ladder.

RELATIVE POWER TRANSMITTING EFFICIENCY OF THE LEVER AND THE SCREW.—The relative power transmitting efficiency of the lever and the screw may be determined by multiplying the power by the distance through which it moved, in each case, separately, and making the products obtained factors of the formula: L:S::SW:LW, in which L is the product obtained by multiplying the power applied to the lever by the distance through which it moved, and S the product obtained by multiplying the power applied to the screw by the distance through which it moved, LW and SW being respectively the weights moved by the lever and by the screw.

In the circumstances with which we are now dealing, LW and SW are equal and the crank handles being of equal length the power moves through a like distance in each case per revolution. Hence the relative efficiency may be shown by comparing the products of the powers by the distances through which they move.

From problems previously worked out we have

seen that a power of 148 lbs. applied through $22\frac{1}{2}$ revolutions erected a ladder in circumstances where lever principles were applied throughout, while 212 lbs. applied through 15.7 revolutions raised a ladder offering equal resistance: $148 \times 22\frac{1}{2} = 3{,}330$, $212 \times 15.7 = 3{,}328.4$. This comparison would make it appear that the screw is slightly superior to the lever as a medium for the transfer of power. This superiority, however, is not real and its appearance here is due to the fact that while it was possible to reduce the whole of the operation with the screw raised ladder to computation, the exact number of revolutions necessary to place the lever raised ladder erect had to be determined by count.

In the comparison just considered the factor 15.7 is derived from the following facts:

(1) The length of the power arm of the ladder with screw device is 20 inches.

(2) The pitch of the screw is 2 inches.

(3) The length of a quarter circle is to a radius as that of a half circle to a diameter.

(4) The ratio of a half circle is to a diameter as 2 is to 3.1416 or as (1) is to 1.5708.

Therefore, in order to erect the ladder, the screw would travel through a distance of 20×1.57 or 31.416 inches. Which at 2 inches to the revolution requires $\frac{31.416}{2}$ or 15.708.

COMPOUND MACHINES.—The lever, the wheel and axle, the pulley, the inclined plane, the wedge, and the screw comprise the traditional simple machines. When two or more of these machines

are combined, the mechanical advantage may be found by computing each separately, or by finding the weight that a given power will support, using one machine alone, and treating the result as a new power acting upon the second machine, and so on.

BUT TWO PRINCIPLES INVOLVED.—It may be observed that there are but two principles involved, that of the lever, on which the wheel and axle are based, and that of the inclined plane which is developed in the wedge and the screw.

Machines are based, for the most part, on the lever principle, for even where the screw is used, the lever is almost universally employed in connection with it, as in the case of the screw raised ladder, in which the crank handles constitute levers.

POWER REQUIRED TO RAISE GROUND REST LADDERS.—In the computations involved, under this heading, the principles of the lever are involved, and the end where the ladder is butted is the fulcrum. A 35-foot ladder weighs $4\frac{1}{2}$ lbs. to the running foot, the weight being distributed uniformly. What resistance must the men raising it overcome? From previous examples we know that the center of gravity is at the middle point of the ladder, or 17.5 ft. from the fulcrum. When the ladder is grasped at a point more than 17.5 ft. from the butt, the principles involved in its raising are those of the lever of the second class. When the men in the progress of pushing the ladder up approach nearer the butt than the middle point, the operation is conducted on the principles of the lever of the third class. If the ladder with which we are now dealing be picked up at a distance of 21 feet

from the butt, or 14 feet from the top, according to common procedure, the weight that the men lift is represented in the formula: P:W::WA:PA, by substitution $P:157\frac{1}{2}::17\frac{1}{2}:21$ or $P=\frac{157\frac{1}{2}\times 17\frac{1}{2}}{21}$ or 131.24. That is, each man lifts a weight of 66 lbs. When they reach a point equidistant from the two ends of the ladder they may be said to sustain the exact weight of the ladder. As the men advance closer to the fulcrum than the middle point of the ladder, the resistance they must overcome is greater than the weight of the ladder. For the weight arm now becomes greater than the power arm. The exact resistance which men raising a ladder have to overcome, at any point in their progress, may be determined by applying the rule: The power arm is the perpendicular distance from the fulcrum to the line in which the power acts; the weight arm is the perpendicular distance from the fulcrum to the line in which the weight acts. The line in which a weight suspended above the surface of the earth acts is always directly downwards. Hence, the weight arm, in this case, is the shortest distance from the middle point of the ladder to a perpendicular at the point of the fulcrum. The power is applied at right angles to the ladder, which renders the power arm the distance from the butt of the ladder to where it is supported.

COMPUTING THE POWER THAT MUST BE APPLIED AT THE POINT OF GREATEST RESISTANCE IN THE WORK OF RAISING A GROUND REST LADDER.—Under the condi-

tions that prevail in the raising of ladders for fire service the greatest resistance is encountered at the time the ladder is at an angle of 45 degrees. This is due to the fact that the men raising a ladder approach the butt more rapidly than the center of gravity of the ladder approaches a perpendicular to the butt until such time as an angle of 45 degrees is reached. While after the angle of 45 degrees is past the center of gravity of the ladder approaches the perpendicular more rapidly than the men approach the butt. Hence, when the ladder is at an angle of 45 degrees the quotient obtained by dividing the product of the weight and the weight arm by the power arm, is greatest.

The formula: P:W::WA:PA is here applicable.

Let the ladder be 35 ft. long and the men raising it 6 ft. tall. When the ladder is at an angle of 45 degrees a line dropped from any point in it will form one side of an equilateral right triangle of which the ladder forms the hypotenuse and the ground the other side. Measurements show that the point where men 6 ft. tall support a ladder is slightly more than 7 ft. from the ground. This being so, the sides of the triangle are each 7 ft. and the hypotenuse the square root of twice the square of 7, which may be said to be 10 ft., and is the length of the power arm and the value of PA in the formula. To find the value of WA in the formula we drop a line from the middle point of the ladder. This line will form one side of an equilateral right triangle, the hypotenuse of which is 17.5 ft. and the other side of which is the value of WA as it is the perpendicular distance from the fulcrum to the line in which the power acts. But a side of an equilateral right triangle is

equal to the square root of ½ the square of the hypotenuse, in this case 12.3 ft. If we assume that the ladder weighs 160 lbs., we may now substitute in the formula P:W::WA:PA, which may be written P:160::12.3:10, or $P = \frac{160 \times 12.3}{10} = 197$ lbs., which represents the maximum weight that men sustain in raising such a ladder.

There are three additional factors that should be considered in determining the actual resistance that is to be overcome in raising fire department ladders.

(1) The upper ends of the beams of such ladders are shod with iron plates, weighing about one pound each. This adds 4 lbs. to the weight that is sustained when the ladder is held at the middle. The length of the weight arm, as regards them, is the total length of the ladder. When a 35 ft. ladder, at an angle of 45 degrees, is supported by men in the usual way, those plates cause an additional weight of 5 lbs. For in such case the distance from such plates to a perpendicular to the horizon at the fulcrum is 25 ft. and the power arm 10 ft.

(2) Such ladders are not rigid, hence the distance from the perpendicular to the fulcrum, to any point in the ladder above that at which it is supported, is slightly greater than shown by computation.

(3) No allowance is made for the additional energy necessary to cause the ladder to ascend, over and above that necessary to sustain it. Factor 3 depends almost entirely on the velocity with which the ladder is impelled.

STABILITY OF THE HOOK AND LADDER

TRUCK.—In previous discussion of bed ladders the question of stability did not arise.

From the viewpoint of the present discussion the truck upon which the ladder is erected is regarded as the base. To take this new base into consideration is necessary, as the ladder is now to be considered as lowered away from the truck, in a line at right angles to the length of the truck frame, and may be lowered so far, in this direction, as to upset the truck.

STABILITY OF TRUCK DEPENDS ON THE CENTER OF MASS NOT BEING CARRIED OUTSIDE A PERPENDICULAR TO THE BASE.—In ordinary use hook and ladder trucks are drawn up a curb, the bed ladder raised to a perpendicular position, then turned one-fourth of a revolution, or 90 degrees, extended, and lowered towards a building. While the ladder is in a vertical position, the line of direction (center of gravity) of both ladder and truck falls half way between the wheels. As the ladder is inclined towards the building the center of gravity of the ladder soon passes outside the wheel base but the stability of the ladder is still secured by the weight of the truck upon which it rests. As the ladder inclines away from the truck, the center of mass of the whole approaches the wheel over which the ladder leans. If a ladder were lowered until the line of direction fell outside the base, the truck would turn over on its side, and the ladder be wrecked. Hence, it is a question of practical importance that fire officers should be able to compute the distance which a ladder may be lowered from any position in which a truck may be drawn up without unduly endangering the apparatus.

EXAMPLE.—A hook and ladder truck weighing six tons has a six-foot spread of wheels. The bed ladder of this truck is 40 ft. long and weighs 20 lbs. to the foot, with a fly ladder 40 ft. long and weighing 10 lbs. to the foot. The turn table of the truck is 5 ft. above the ground, and the ladder is extended so it reaches a height of 75 ft.

(In discussion of this problem the force that sustains the stability of the ladder will be called the weight, that which tends to overthrow that stability will be called the power.)

In this problem there is presented an example of conditions under which the power necessary to overthrow stability does not vary with the height. When an extension ladder is lowered at right angles to the truck frame, the truck will retain its stability until the line of direction falls outside the wheel base, when it will fall over irrespective of the height of the wheels.

Under the conditions stated the weight arm is one-half the width of the wheel spread, or three feet, while the weight that must be raised in order to overthrow the equilibrium one-half of six or three tons and the power is twelve hundred pounds. Hence the formula P:W::WA:PA may be written:

$$1200:6000::3:PA, \text{ or}$$

$$PA = \frac{6000 \times 3}{1200} = \frac{18000}{1200} = 15$$

That is, a truck such as is here described, will turn over when the center of gravity of the ladder falls 15 feet from the center of the turn table, or 12 feet outside the wheel over which the ladder leans.

To show the distance which such a ladder may be

stationed from a building, it is necessary to find the center of gravity of such a ladder, so extended. In working out this the weight of each section of the ladder must be taken into account separately.

The bed ladder weighs 40×20 or 800 lbs., the fly 40×10 or 400 lbs. The center of gravity of the bed ladder is 20 ft. from the base, while the fly being extended 30 ft. its center of gravity is 50 ft. from the base of the bed ladder. The total weight of the ladder is 1,200 lbs.. Hence the center of gravity of the ladder when thus extended, is

$$\frac{20 \times 800 + 50 \times 400}{1200} \text{ or } 30 \text{ ft.}$$

That is, the center of gravity of the ladder is 30 ft. from the base of the bed ladder.

Since a ladder, of the weights and dimensions specified, may be inclined to a position in which a point 30 ft. from its base will coincide with a perpendicular erected fifteen feet from the center of the turn table, it follows that the total distance which the ladder reaches when in this position is shown in the formula 30:15::75:d, in which d represents the total distance bridged. This formula may be changed to:

$$d = \frac{15 \times 75}{30} \text{ or } \frac{75}{2} = 37.5 \text{ ft.}$$

ANGLE FROM PERPENDICULAR WHICH THE LADDER MAKES WHEN IN THE POSITION STATED IN THE LAST EXAMPLE.—The angle which a ladder, placed as just stated, will form with the wall against which it leans may be found as follows:

Since the base of the right triangle formed is 37.5 ft. and the hypotenuse 75 ft., the length of the other side is shown in the formula $\sqrt{75^2 - 37.5^2}$ or $\sqrt{5625 - 1406}$ or $\sqrt{4219}$, that is, 65 ft.

From this data it may be found (geometrically) that the ladder makes an angle of 30 degrees with the perpendicular. For if the hypotenuse of a right triangle is twice as long as the base, the angle which the hypotenuse makes with the base is double that which it (the hypotenuse) makes with the other side. Hence, the ladder makes an angle of 30 degrees with the perpendicular, and 60 with the horizontal.

ANGLE TO WHICH AN EXTENDED LADDER MAY SAFELY BE LOWERED.—While in theory a ladder may safely be lowered into the position stated in the preceding example, in practice it would not be well to permit an extended ladder to be placed at an angle of more than 25 degrees from the perpendicular, as at any broader angle it would be, for the following reasons, unsafe:

(1) The frame work of a truck not being rigid the front part is raised some distance before the stabilizing effect of the rear becomes wholly effective.

(2) A ladder may be heavier, or a truck lighter, than here stated.

(3) The wheels towards the building may be on a lower plane than those on the other side of the truck.

(4) Although, owing to the great sway of a truck ladder, it is deemed avisable to regard the weight arm as only one-half the wheel spread in lieu of the

whole spread as would be allowed if the ladder were rigid, still an additional safety factor is deemed necessary.

The question of how far an extended ladder may be inclined, when the line of direction of ladder falls in a right angle to the frame drawn through the center point of the turn table, is a question presented in practice only where it is impracticable to bring a truck reasonably close to a building.

POSITIONS IN WHICH LADDERS SHOULD BE PLACED.—The distance from a building at which a ladder should be placed where a selection may be made, has been discussed in the firemanic world, and a good practical rule adopted. This rule, however, lacks precision, definiteness and that scientific accuracy so essential to the development of close and accurate reasoning.

The rule adopted is: The butt of a ladder should be placed a distance, from the wall against which it (the top of the ladder) is to rest, equal to the number obtained by dividing the length of the ladder in feet by 5 and adding one. By this rule you get, for the shortest ladder used, a base of $\frac{20}{5} + 1 = 5$ ft., and for the longest $\frac{80}{5} + 1 = 17$ ft. In this connection it must be remembered that in taking positions for extension ladders, it is the wheel closest the building that measurements are taken from. So that to all results obtained for ladders above 40 ft. 3 ft. should be added. Hence the 80 ft. ladder is at

the same angle as if the base of it fell 20 ft. from the wall against which it rested.

POSITIONS OF LADDERS STATED ACCURATELY.—As in practice ladders are never set up in accordance with actual measurements, it seems best to state the matter in a form that men may readily learn to measure by sight.

Ladders should be so placed that when they rest against the wall of a building they form an angle of 16 degrees with the wall against which they rest (provided the wall is perpendicular).

It may be shown geometrically and by measurements, that when one angle of a right triangle is an angle of 16 degrees, the side of the triangle opposite that angle is equal in length to one-fourth the hypotenuse.

It may be seen that for 20 ft. and 80 ft. ladders, both methods give similar results, this method being consistent while the old method is inconsistent. The variance in the old method shows most in the case of 35 and 45 foot ladders. With a 35 ft. ladder $\frac{35}{5} + 1 = 8$, while $\frac{35}{4} = 8.75$, showing a variance of 9 inches in the case of a 35 ft. ladder.

With a 45 ft. ladder $\frac{45}{5} + 1 = 10$, with 3 ft. allowed on account of measurement being taken from wheel gives the ladder an angle equal to that which it would have if placed 13 ft. from building. While $\frac{45}{4} = 11.25$ ft., according to method here proposed.

The rule here proposed has the advantage of being accurate, consistent and scientific. And if the old method be substantially correct, this method must of necessity be correct.

STABILITY OF GROUND REST LADDERS.—A ladder reclining against a perpendicular may fall in either of two ways. (1) The butt of the ladder may slide away from the perpendicular. (2) The top of the ladder may be forced away from the perpendicular, and the ladder thrown over.

EFFECT OF ANGLE AT WHICH A LADDER IS PLACED.—The greater the angle which a ladder makes with the perpendicular the greater the resistance it offers against being hurled away from the perpendicular, and the less resistance it offers to sliding away at the base.

EFFECT OF PLACING THE WEIGHT HIGH ON THE LADDER.—The higher a weight is placed on a ladder the greater the force necessary to overturn it, while the less the force required to cause it to slide away.

EFFECT OF THE MAGNITUDE OF THE WEIGHT.—The greater the weight that is placed at any point on a ladder the greater the force that is necessary to overturn it. A weight placed above the middle point of a ladder renders the ladder more likely to slip away, while if it is placed below the middle point it renders it less likely to slide.

Where a weight is placed above the middle point of a ladder the proportion of the weight that presses against the perpendicular is greater than the proportion of the weight of the ladder that presses against

the perpendicular and the relative proportion that rests on the base is less. This renders the ladder more likely to slide.

EFFECT OF THE NATURE OF THE SURFACE ON THE LIKELIHOOD OF A LADDER SLIDING.—Owing to the fact that the nature of the surface upon which a ladder rests is the prime factor in determining its security against sliding away at the bottom, it is impracticable to compute the weight that a ladder placed at a given angle will sustain, or the height to which a stipulated weight may be carried on a ladder placed at a designated angle.

FORCE WHICH AN INCLINED PLANE EXERTS UPON A PERPENDICULAR AGAINST WHICH IT RESTS.—The force which an inclined plane, of uniform weight, exerts upon a perpendicular against which it rests is equal to the quotient obtained by dividing, the product of the weight of the plane by one-half the base of the right triangle formed by the inclined plane, the wall and the ground upon which they rest, by the length of the plane.

EXAMPLE.—A ladder 35 ft. long, of uniform weight, which amounts to 160 lbs. rests against a wall so as to form an angle of 16 degrees with the perpendicular, exerts on the wall a force equal to the result obtained from the formula: P:W:: WA:PA. In which P represents the power (i.e., the force exerted against the wall), W the weight of the ladder, WA the horizontal distance from the center of gravity of the ladder to a vertical erected

at the butt of the ladder, and PA the length of the ladder.

The value of WA in the formula is based upon the lever principle, before stated, that the weight arm is the perpendicular distance from the fulcrum to the line in which the weight acts.

As was pointed out, in the discussion of the angle at which ladders should be placed, where a right triangle has one of its angles an angle of 16 degrees the side opposite that angle is equal to ¼ the hypotenuse. Hence the base of the triangle treated here is $\frac{35}{4}$ or 8.75 ft.

The center of gravity of the ladder being at its middle point is 4.375 ft. from the wall and a like distance from a perpendicular to the base, and the value of WA in the formula is 4.375.

And the formula may be written:

$$P : 160 :: 4.375 : 35, \text{ or its equivalent:}$$

$$P = \frac{160 \times 4.375}{35}$$

That is, P = 20 lbs., which is the force requisite to lift the top of the ladder away from the wall.

If a man weighing 160 lbs. stands at the middle point of this ladder the only change in the values of the formula will be that the value of W becomes 320, and the value of P 40 lbs. That this is so, is clear from the fact that center of gravity of the ladder is at its middle point, and when the man stood at that point the center of gravity still continued there.

Where the man stands at any other than the middle point of the ladder it becomes necessary to

find the center of gravity of the whole before going into the question of the force exerted on the wall. In such cases the center of gravity will be found to be between the middle of the ladder and the point where the man stands, and a distance from the middle point proportionate to the respective weights of the ladder and the man.

Thus, if a man weighing 160 lbs. stands on the ladder here considered at a distance of 25 ft. from the butt, the center of gravity of the whole will be

$$17.5 + \frac{7.5}{2} \text{ or } 17.5 + 3.75, \text{ that is, } 21.25 \text{ ft.}$$

Since the ladder is inclined at an angle of 16 degrees the base of the right triangle formed by dropping a perpendicular from a point on the ladder 21.25 ft. from the butt $\frac{21.25}{4}$ or 5.3125, and this is the value of WA in the formula P:W::WA:PA, which formula may now be written:

$$P:320::5.3125:35$$

$$\text{or } P = \frac{320 \times 5.3125}{35} = \frac{1700}{35} = 48.6 \text{ lbs.}$$

Where the weight of the ladder is greater or less than that of the man standing upon it, and he stands at any other point than at its middle, it will be better to compute the force which each exerts against the perpendicular (wall) separately.

In computing the weights separately, in the present case, the value of WA in the formula becomes $\frac{25}{4}$

or 6.25, and the formula:

$$P = \frac{160 \times 6.25}{35} = 28.6$$

Which, added to the 20 which the ladder of its own weight exerted, makes a total of 48.6 lbs.

PRESSURE AT WHICH A STREAM MAY BE OPERATED FROM A GROUND REST LADDER.—A line with a $1\frac{1}{2}$ inch nozzle is being operated on a 35 ft. ladder at a distance of 28 ft. from the butt. The ladder weighs 160 lbs., and a man weighing 160 lbs. is standing at a distance of 25 ft. from the butt and it is desired to determine what pressure may safely be placed on the line, the ladder being set at an angle of 16 degrees.

For the purpose of determining this, the value of the factors in the formula: P:W::WA:PA, are W 48.6 lbs., which is the force the top of the ladder exerts against the wall. WA 35 ft. and PA 28. An additional factor has to be considered in problems of this kind. That is, the area of the nozzle from which the stream is discharged. A convenient way of dealing with this new factor is to multiply PA in feet by the area of the nozzle in square inches, and stating the product as PA′.

This done, we may subtitute P:W::WA:PA′ for P:W::WA:PA, and by substituting the values get in this case: P:48::35:28 × 1.77, which may be written:

$$P = \frac{48 \times 35}{28 \times 1.77} = \frac{1680}{49.5} = 34 \text{ lbs.}$$

With a $1\frac{1}{4}$ inch nozzle the value of the other fac-

tors remaining unchanged the formula becomes:

$$P = \frac{48 \times 35}{28 \times 1.23} = \frac{1680}{34.4} = 49 \text{ lbs.}$$

With a $1\frac{1}{8}$ inch nozzle the formula becomes:

$$P = \frac{48 \times 35}{28} = 60 \text{ lbs.}$$

That the formula is slightly different where a $1\frac{1}{8}$ inch nozzle is used from the formula with other sizes of nozzles, is due to the fact that the area of a $1\frac{1}{8}$ inch nozzle is approximately 1 square inch.

Wherever a problem of this nature is encountered it is first necessary to find the force with which the top of the ladder rests against the wall. Treating this as the weight, the total length of the ladder as the weight arm, and the distance from the butt of the ladder to the point where the line is operated multiplied by the area of the nozzle as the power arm, there should be no difficulty in determining the reaction which the ladder will withstand.

If a $1\frac{1}{2}$ inch stream is operated at a distance of 21 ft. from the butt, the man standing $3\frac{1}{2}$ ft. lower, the value of the factors in the formula are W 40, WA 35, and PA 21×1.77 or 37, and the formula may be written:

$$P = \frac{40 \times 35}{21 \times 1.77} = \frac{1400}{37} = 38 \text{ lbs.}$$

With a $1\frac{1}{8}$ inch nozzle operated 21 ft. from the butt, the ladder, man, and man's position upon the ladder being the same as in the case immediately preceding, the value of the factors in the formula are:

$$P = \frac{40 \times 35}{21} = 66.6$$

In practice a second man stands at a point below where the weight bends the ladder. His weight and that of the charged line would increase the theoretical stability of the ladder about 50 per cent. Thus the maximum theoretical pressure that could be placed on a line using a $1\frac{1}{2}$ inch nozzle is $37.8 + 18.9$ or 56.7 lbs. As, in operations of this nature, a liberal factor of safety is desirable, it seems that where lines are to be used from ground rest ladders, the butts of ladders should be placed farther from the walls against which the ladders are to rest than when they are used for other purposes, and that the old rule of divide the length of the ladder by 5 and add 1 should be modified so as to exclude circumstances under which streams are to be operated from ladders.

In this connection it should be noted that when ladders are used for rescue, and such work, the smaller the angle which a ladder makes with the perpendicular the more convenient for climbing and for carrying persons down; therefore, ladders to be used for this class of work should have their bases placed as close to the wall against which they are to lean as is consistent with the safe conduct of operations of the character being conducted, while, when lines are to be operated from ladders a considerably broader base should be allowed.

It might be suggested that 12 degrees is a sufficient angle at which to place ground rest ladders to be used in climbing. This would give a base of

about one-fifth the length of the ladder. But when streams are to be operated from them, ladders should be set at an angle of 20 degrees, at which angle the base would be about .3 the hypotenuse.

In the case of mounted ladders the angle of 16 degrees should be continued for two reasons: First, the ladder being capable of extension may be employed at different heights, while the width of base cannot be changed; second, the weight of the truck furnishes such stability to the ladder that there is no possibility of its being overthrown by the reaction of a stream.

STABILITY OF WATER TOWERS.—A water tower weighing 7 tons has an effective wheel spread of 7 feet. When the tower is extended there is a vertical distance of 64 ft. from the ground to the level of the nozzle. A two-inch nozzle being used, it is desired to find the pressure at which it could safely be operated.

In this case we are again dealing with lever principles, the power arm is the height of the tower, the weight arm the wheel spread, the weight ½ the total weight of the tower, while the power is the reaction caused by the operation of the stream.

Hence, if P represents the power, W the weight, WA weight arm and PA power arm, the pressure at which the tower could operate is represented in the formula: P:W::WA:PA, which by substitution becomes P:7,000::7:64 × 3.1416, for 3.1416 is the area in square inches of a nozzle having a diameter of 2 inches.

Or the formula may be put:

$$P = \frac{7{,}000 \times 7}{64 \times 3.1416} = 243 \text{ lbs.}$$

That is, in theory, such a tower could be operated under a pressure of not more than 243 lbs. on the nozzle.

It would be unwise, however, to operate such a tower at more than 1/3 this pressure until tormentors were put in place and properly secured.

There are a variety of reasons why a tower should not be operated at a pressure approximating that which, in theory, it will withstand.

Amongst those reasons are the following:

(a) The reaction (back pressure) caused by a stream is, owing to pulsations, not a steady pressure, and the effect of vibration is magnified by the pliability and the excessive length of the power arm.

(b) It frequently happens that when high pressures are required the wheel on the side of the tower towards which the stream is being discharged is on a higher plane than the one distant from the fire building.

(c) The frame of the tower not being rigid, the front wheel may be raised a considerable distance from the ground before the full weight on the rear wheels become effective.

(d) A substantial factor of safety is desirable where heavy apparatus is employed.

Where, however, tormentors are thrown out and properly secured, the highest pressure, ordinarily available for fire service, may safely be applied to a water-tower correctly stationed and secured.

STABILITY OF PIPE HOLDERS.—Pipe hold-

ers may be divided, for the purpose of discussion, into two classes.

(a) The older types, of which the "Perfection" is the most widely known.

In the construction of this type of holder the factor of stability was not developed. What was sought was a convenient contrivance that would sustain the reaction on the line and not impede the direction of streams. Hence the ground rest provided was the bluntly tapered end of a bar.

(b) Among the types, more recently developed, the one most frequently used is called the "Paradox." In this holder stability is secured by placing the ground end of the pipe stick in the middle of a broad low base.

Stability is a very important factor in fire-fighting, and the value of a broad base in securing stability rarely finds a more impressive medium of illustration than that furnished by the "Paradox" pipe holder.

LINES SECURED BY "PARADOX" PIPE HOLDERS.—A line secured by a "Paradox" pipe holder may safely be operated at any pressure commonly available for fire service, and one man by standing on the holder platform will furnish such stability that the stream may be turned in any direction. Hence, there is little practical reason for computing the stability of the contrivance. But as it is part of fire department equipment the method of computing its stability may be stated. While a stream is discharged in a line with the pipe stick (which is the ordinary method of operation), the greater the pressure the greater the stability. If, however, the stream be discharged at right angles to

the line of the pipe stick, the formula P:W::WA:PA is applicable. And in this formula P is the reaction due to the discharge of the stream, W ½ the weight of the holder and of so much of the charged line as is mounted upon the holder, WA the width of the holder platform, and PA the vertical distance from the ground to the level of the discharge end of the nozzle.

PUMPING APPLIANCES

PARTS OF A PUMPING ENGINE.—A pumping device in which the potential energy contained in a heated medium is converted into mechanical energy and exerted upon another medium, may, for the purpose of discussion, be treated under three headings.

(1) The Engine.—That is, the part in which the heat energy is converted into measurable power motion along definite lines, or along lines susceptible to control.

(2) The Machine.—This consists of the parts which transmit the power to the medium upon which the power is exerted.

(3) The Pump.—This includes the parts through which the medium, upon which the power is to be exerted, (i.e., water) flows to the device that acts directly upon the medium, and the surfaces that enclose the medium while the energy is being transferred to it.

EXTENT TO WHICH THE NATURE OF OUR DUTIES SHOULD LIMIT OUR STUDIES OF THIS PHASE OF THE SUBJECT.—The nature of the work we are called upon to perform envelopes within narrow limits the study of this branch of the subject to which we may advantageously direct our inquiry.

Heat is always the source of the energy utilized, while the medium to which it is desired to transfer the energy is invariably water. Hence, our concern is to determine the type of mechanical device best fitted, with least waste of energy and least wear on

mechanical parts, to transmit the potential energy of the heat to the water.

TYPES OF ENGINES AND OF PUMPS.—There are, at present, in the field of fire-fighting two types of engine, each of which occupies such a prominent position that it demands special consideration. These are the steam and the internal combustion engine. For similar reasons two types of pump, the reciprocating and the centrifugal, demand consideration.

The reciprocating pump was, while the centrifugal was not, well adapted for operation in conjunction with the steam fire engine, as will be made clear in the discussion to follow. The reverse prevails in the case of the internal combustion engine, as we will endeavor to show by a discussion of the causes.

THE STEAM FIRE ENGINE.—In principle the steam engine is a device for utilizing the elasticity and expansive energy of steam as an impelling force. It is a real heat-engine transferring the potential energy, with which heat has endowed the steam into force that may be directed along definite lines, and utilized to alter the relative positions of bodies (i.e., for the performance of work). As used in fire engines it has accessories for increasing its (the steam engine) efficiency and adapting it to this special use. The parts that it is necessary to know about, in order to understand the mechanical operation that takes place, are the cylinder, piston, valve ports, and valves.

MECHANICAL OPERATION OF A STEAM ENGINE.—When the piston of a steam engine is at one end of the cylinder, that is, when the whole en-

gine comes to a dead stop, preliminary to changing its direction, the steam valve at the same end of the cylinder as the piston commences to open and admit steam, which pushes the piston towards the opposite end of the cylinder. Meanwhile the valve, of the exhaust port, on the end of the cylinder distant from the piston opens and allows the steam, the energy of which has been expended, to escape. When the piston reaches the end of the cylinder opposite that at which it was at the commencement of the discussion, the steam valve, at the end of the cylinder at which the piston now is, opens, admitting steam on the side of the piston opposite to that on which it operated during the preceding stroke. At the same time the exhaust valve at the end of the cylinder into which the steam was first admitted opens, allowing the steam on that side to escape. In this manner steam is admitted first on one side of the piston, again on the other. And thus the piston is pushed back and forth alternately, making each stroke a power stroke. This work is performed by the steam at the expenditure of the potential energy which it possesses by reason of its highly heated condition, and in performing that work it loses the pressure due to the heat which it possessed before the work was performed.

ADAPTABILITY OF THE STEAM ENGINE FOR OPERATION WITH RECIPROCATING PUMP.—Much has been written, by way of instructions to operators, and by various manufacturers in laudation of their particular products, but there is dearth of dispassionate discussion on the question of the adaptability of the principles involved in the various types to the conditions prevailing in fire

service. Whatever medium is employed for the generation of power, machine parts can be so arranged as to transmit that power to the matter upon which it is to be exerted, and the loss due to friction enroute will be substantially equal whether the power be generated by steam or by combustion within the engine. Hence, the questtion in which we are especially interested is whether the arrangement of the mechanical parts is such as to bring the power to the contrivance that is to act directly upon the matter to be propelled (in this case water) at a velocity of motion suitable to the propulsion of such matter.

The steam engine is pre-eminently fitted for coupling to the reciprocating pump because the highest efficiency of the steam engine is attained at comparatively low rates of speed. While in the propulsion of water the lower the velocity of motion the less the resistance encountered. The principle upon which the reciprocating pump operates is to develop and maintain pressure so that flow may result therefrom. Hence, it is apparent that the more slowly the contrivance maintaining the pressure moves the less waste of energy involved in the process.

This adaptability of the steam engine for economical operation at low velocity is in no small degree responsible for the reciprocating pump having come victorious from the struggle for survival, an expensive struggle that would never have taken place had the scientific principles involved been fully understood by those who advocated the use of any form of centrifugal pump in connection with a reciprocating steam engine.

The steady push-like manner in which power is transmitted to the piston of a steam engine (power

being applied at every point in every stroke) enables the steam driven engine to operate on the non-elastic water without causing such shock and vibration as to materially lessen the working life of machinery.

REASONS WHY CENTRIFUGAL PUMPS DO NOT OPERATE ECONOMICALLY WHEN DRIVEN BY STEAM POWER.—Centrifugal pumps do not give satisfatcory service when driven by reciprocating steam engines, because the principle on which water is impelled by them is diametrically opposite to that involved in the operation of reciprocating pumps, for the driving of which steam is pre-eminently fitted.

In the case of reciprocating pumps, flow results directly from pressure, developed and maintained in the first instant and directly by the pump, while by the operation of centrifugal pumps impetus is first given to the water and the kinetic energy thus imparted is converted into potential energy in the form of pressure. In other words, in the reciprocating pump potential energy is manufactured directly from the push of the displacer (i.e., the plunger) on the water, while in the centrifugal pump the energy is first manifest in the water in kinetic form and is later changed into potential in the casing or vortex chamber, the change from kinetic to potential energy being brought about by retarding the velocity of the flow.

Operating on this principle, it is evident that the most economical centrifugal pump is that which can develop the highest velocity of flow in a given length of pipe. It is also apparent that high velocity of flow can be developed most economically by a generating

medium the efficiency of which increases with increase in its velocity of motion.

INTERNAL COMBUSTION ENGINES.—The internal combustion engine is a heat engine in even a broader sense than the steam engine, for the heat which produces the operating energy is generated within the cylinder of the latter type, while in the former the heat is absorbed by the water while it is still contained in a boiler separate and distinct from the engine, in the sense that the term engine is used in this work.

ECONOMY OF THE INTERNAL COMBUSTION ENGINE.—The relative economy of the mechanical contrivance known as the internal combustion engine, is supposed to be due to the fact that the heat being generated within the chamber in which the power is applied the waste of heat is reduced to a minimum.

Prior to the development of the gas engine, the steam engine was the most economical of all heat operated devices. Yet the highest returns obtainable from a steam engine is 18 per cent of the heat units contained in the fuel consumed. In the internal combustion engine as high as 40 per cent of the heat energy contained in the energizing medium has been reproduced in the form of mechanical energy.

REASONS WHY A GREATER PERCENTAGE OF HEAT ENERGY CANNOT BE MADE AVAILABLE FOR MECHANICAL WORK.—There is considerable diversity of opinion as to the reasons for the great waste of energy involved in the process of converting the potential energy of fuel

into kinetic energy in a form available for the performance of useful work.

The dissipation of energy between the combustion of fuel and a point where the mechanical energy may be measured has been the subject of long and profound scientific study in connection with the steam engine. From the data available, and the best analysis of the facts, it is estimated that about 30 per cent of the potential energy of fuel is not absorbed by the water, but is dissipated by way of the smoke flue in the form of unconsumed carbon, or as heat. The heat that passes off in this way does useful work only in improving the draught. An amount equivalent to about 15 per cent of the total energy of fuel passes off by conduction through and convection (improperly called radiation) from boilers, steam pipes, ports, cylinders, etc., while a considerable amount of energy is used up in overcoming back pressure due to the early closing of exhaust, and the early opening of steam ports. And a still further loss is due to the impossibility of uitlizing the latent heat of vaporization for the performance of mechanical work.

DISPARITY BETWEEN THE HEAT ENERGY CONTAINED IN GAS AND THE MECHANICAL ENERGY PRODUCED IN THE INTERNAL COMBUSTION ENGINE BY ITS USE. —No substantial progress has been made towards a determination of the manner in which the 60 or more per cent of the heat energy contained in fuel, used in the internal combustion engine, is dissipated. The fact, however, that an increase in the temperature of the water in the cylinder jacket materially increases the efficiency of a gas engine indicates that a sub-

stantial part of the loss is due to the passing of heat through the cylinder walls. The greatest part of the loss appears, however, to be due to the incomplete combustion of the fuel, in overcoming the resistance necessarily incurred on the compression stroke, and in the fact that considerable heat is carried off in the exhaust.

ECONOMY OF OPERATION.—The four prime requisites for economy in operation are:

(1) Greatest possible cylinder volume with the least possible cooling surface (purpose attained; conservation of heat).

(2) High speed. (The energy of the heat being conveyed by explosive-like erruptions, the power is delivered in the form of blows, thus entailing great waste unless the explosions occur in rapid succession. The fact that there is but one explosion for four strokes renders high speed very essential to economy.)

(3) Long stroke. (Less waste of energy in overcoming back pressure, as there are fewer strokes for the development of a given power.)

(4) High compression. (The closer together particles of matter are when ignition takes place the more violent the explosion.) The expenditure of energy necessary to the development of compression more than offsets the advantage derived from the increase in explosive force where the compression exceeds 100 lbs. per square inch.

MEDIUM THROUGH WHICH POWER IS TRANSFERRED TO THE PISTON.—The generation of power is accomplished by the expansion of the nitrogen of the air and the watery vapor pro-

duced by union of the oxygen in the air and the hydrogen in the gas.

The expansion of these substances is accomplished by the combustion of the oxygen in the air and the hydrogen and carbon in the gas.

RECIPROCATING PUMP ILL ADAPTED TO OPERATE IN CONNECTION WITH INTERNAL COMBUSTION ENGINE.—Owing to the high speed that must be maintained in order to ensure economy of operation in connection with the internal combustion engine, the reciprocating pump cannot be connected directly to it. Hence it is necessary to transmit the power through cog gears, sprocket chain or some equivalent device. The result is that the machinery is more complicated, more parts are subjected to wear, with the result that repairs are needed more frequently, are more extensive and more difficult to make. But more far-reaching in determining the impracticability of employing the reciprocating pump in connection with the internal combustion engine is the vibration and shock unavoidably delivered by stroke-like impacts conveyed by a flat surface displacer to an incompressible substance like water.

CENTRIFUGAL PUMP OPERATION IN CONNECTION WITH INTERNAL COMBUSTION ENGINE.—The question of the most suitable type of pump to use in connection with the internal combustion engine is one of paramount importance to the firemen of the immediate future, owing to the fact that fire department pumping equipment is undergoing a change from steam to internal combustion engines. The most suitable types will not be

provided unless we approach the subject with clear understanding of the scientific principles involved.

It should be understood, at the outset, that it is a physical impossibility, and well recognized to be so by science, to construct a centrifugal pump that will force a given quantity of water against a definite pressure with the expenditure of an amount of power no greater than that by which the same amount may be forced against a like pressure by a well designed and carefully constructed displacement pump, when operated at a moderate rate of speed. This is due to the fact that by the operation of the reciprocating pump the impulses, by which the plunger delivers to the water the power with which it is impelled, are received in such manner that the energy appears directly in potential form where its value may be determined by a measurement of the volume delivered and the pressure maintained. Furthermore, there is no waste in the water end of a reciprocating pump except that incident to the flow of water, and that waste cannot be obviated by any method of propulsion yet devised.

Where the centrifugal pump is used the energy on first reaching the water appears in kinetic form, and must be altered so as to appear as potential energy before it can be made available for use in fire streams. With the best possible design there must be some waste in the change from kinetic to potential energy. For it is a well recognized fact of physical science that there cannot be a change from potential to kinetic energy or vice versa without an expenditure of force.

RELATIVE EFFICIENCY OF DISPLACEMENT AND CENTRIFUGAL PUMPS.—A well

designed and skillfully constructed reciprocating pump will, while new, show an efficiency of 90 per cent as against 86 for the best type of centrifugal pump. The reciprocating pump, owing to its delicate parts, deteriorates so that after a few years it is more wasteful than a well designed centrifugal pump, the efficiency of which does not vary with use.

The great difficulty with the centrifugal pump is that a variation so slight that it could be detected only by an expert may destroy its efficiency. This is due to the nicety of design that is necessary to prevent shock and eddying, or vortices, as they are called, both of which are destructive of energy.

POINTS IN WHICH THE CENTRIFUGAL PUMP EXCELS THE RECIPROCATING.—The centrifugal pump is lighter, more compact, more enduring and requires practically no repairs to the pump proper. As this type of pump runs without shock or excessive vibration, the wear of the machinery transmitting the power is reduced to a minimum, which results in long life and renders the cost of repairs slight.

TESTS TO WHICH CENTRIFUGAL PUMPS INTENDED FOR FIRE DEPARTMENT SERVICE SHOULD BE SUBJECTED BEFORE ACCEPTANCE.—Centrifugal pumps intended for fire service should be subjected to exacting tests, and tried out under a great variety of conditions. But where they display good, uniform results under varying conditions, they should be preferred to those of the reciprocating type if their efficiency equals 80 per cent of that shown by the latter.

CENTRIFUGAL PUMPS

REASONS WHY A DESCRIPTION OF THIS TYPE OF PUMP IS DEEMED DESIRABLE.—A brief description of this pump is here given for the following reasons:

(1) It is a type of pumping device the principles of which are comparatively new to firemen.

(2) It is a pump that seldom or never requires repairs, thus the internal structure is rarely exposed so there is little opportunity for becoming familiar with it by observation.

(3) As the impracticability of operating reciprocating pumps, in connection with internal combustion reciprocating engines, becomes manifest the question of determining the best type of centrifugal pump for operation in connection with this kind of power generator will constitute one of the two most important questions, in the matter of providing equipment, that firemen will be called upon to answer. (The other important determination is the kind of device best suited for raising bed ladders.)

(4) For these reasons every fire officer should have a general knowledge of centrifugal pump construction and type characteristic so as to be able to make an intelligent selection of type and size to fit any given set of conditions.

HISTORICAL DEVELOPMENT.—The centrifugal pump in its modern form is a development of the last 20 years, although as a type it is by no means new. The invention of the centrifugal pump is accredited to the celebrated French engineer Denis Papin, who turned out the first pump of this kind about 1703. Although the principle appears to have

been much experimented with, there was no practical machine of this type until the production of the Massachusetts pump about 1818. From this time on improvements were gradually made in the centrifugal pump until by 1852 an efficiency as high as 64 per cent had been attained against a pressure head of 5 feet, and 45 per cent against a head of 15 feet, but at this time the maximum head for practical operation was 40 feet.

About the year 1901 it was found that the centrifugal pump was simply a water turbine reversed, and when designed on similar lines was capable of pumping against high pressures, and with an efficiency approximating that shown by the best type of reciprocating pump. Since that date great progress has been made both in design and construction, until at the present time centifugal pumps show an efficiency as high as 90 per cent, and are capable of handling as high as 150 lbs. of pressure with a multi-stage pump, and practically any head by coupling multi-stage pumps. Furthermore, there is no very marked loss of efficiency when working against high pressures, as was the case with the earlier pumps of this type.

The advantages of the centrifugal over the displacement types are greater smoothness of operation, freedom from water hammer or shock, absence of valves, simplicity and compactness, and its adaptability for driving by direct connection to modern high-speed prime movers, such as steam turbines, internal combustion engines and electric motors. Under conditions favorable to the centrifugal pump its first cost should be as low as one-third that of a reciprocating pump, of equal capacity, and the floor

space occupied one-fourth that of the latter.

For small quantities of water discharged against high pressure, or where the source of power is by a reciprocating steam engine the reciprocating pump is preferable to the centrifugal type, as the latter would require more compounding, under the circumstances, than its other advantages would compensate for.

PRINCIPLES OF OPERATION.—The principle on which the original centrifugal pumps operated is that when water was set in motion by a paddle wheel, the centrifugal force created forced the water outward from the center of rotation. The first important discovery along these lines was that the efficiency depended chiefly on the form of the blade of the rotating paddle wheel, or impeller, as it later came to be called, and the shape of the enveloping case, and that the best form of blade was a curved surface opening in the opposite direction to that in which the impeller revolved, and for the case was a spiral form, or volute. The next important step was a discovery of the value of compounding, that is, leading the discharge of one centrifugal pump into the suction of another similar pump.

In its modern form, the power applied to the shaft of a centrifugal pump is transmitted to the water by means of a series of curved vanes radiating outward from the center and mounted together so as to form a single member, called the impeller. The water is picked up at the inner edges of the impeller vane and rapidly accelerated as it flows between them, until when it reaches the outer circumference of the impeller it has absorbed practically all the energy that has been applied to the shaft.

IMPELLER FORMS.—There are two general forms of impeller, the open and the closed types. In the former the vanes are attached to a center hub but are open at the sides, revolving between two stationary side plates. In the closed type the vanes are formed between two circular disks forming part of the impeller, thus forming closed passages between the vanes, extending from the inlet opening to the outer circumference of the impeller. The friction loss with an open impeller is considerably greater than with one of the closed type, and consequently only pumps of the latter design display high efficiency.

KINETIC ENERGY CONVERTED INTO PRESSURE.—As the water leaves the impeller with a high velocity, its kinetic energy forms a considerable part of the total energy, and the efficiency of the pump therefore depends largely on the extent to which this kinetic energy is converted into pressure in the pump casing.

In some forms of pump no attempt is made to utilize this kinetic energy, the water simply discharging into a concentric chamber surrounding the impeller, from which it flows into a discharge pipe. The result of such an arrangement is that only the pressure generated in the impeller is utilized and all the kinetic energy of the discharge is dissipated in shock and eddy formation.

VOLUTE CASING.—This loss of kinetic energy may be very largely avoided by placing the impeller so that the sectional area increases uniformly, and increasing the diameter of the casing as it leads from the impeller, making the velocity of flow constant in

the impeller chamber and causing the velocity of flow to diminish gradually in the volute casing.

A form of simple volute casing pump is, perhaps, the kind that will prove most suitable for fire service, as higher efficiency than is attained in them, can be secured only by the addition of parts that make pumps too heavy and cumbersome. Or by the employment of diffusion vanes that limit the efficiency to a specific velocity of flow.

VORTEX CHAMBER.—The vortex or whirl-pool chamber pump is an improvement on the volute chamber type, and for service on fire boats, where weight is not the controlling factor, it should prove a most suitable pump. In this type the impeller discharges into a concentric chamber considerably larger than the impeller, outside of and encircling which is a volute chamber. The effectiveness of this arrangement depends on the principle of the conservation of angular momentum. By this device after the water leaves the impeller no turning movement is exerted on it and consequently as a given mass of water moves outward, its speed decreases to such an extent as to keep its angular momentum constant. For a well designed vortex chamber, the velocity of the water at the outside of the diffusion space is less than the velocity of the water as it leaves the impeller in the inverse ratio of the radii of these points, of the chamber, and if the ratio be large, a great part of the kinetic energy of the discharge will be converted into potential energy in the form of pressure. Hence this method of diffusion is well adapted to small impellers of high-speed pumps, since the ratio of the outer radius of the diffusion chamber to

the outer radius of the impeller may be made large without unduly increasing the size of the casing.

TURBINE PUMPS.—Although the turbine is a centrifugal pump and the general principles upon which it is operated are the same as that involved in other makes of pumps of this type, yet as the purpose is accomplished in a somewhat different manner, it seems best that the discussion of this pump be distinct from others.

It is a well recognized principle of hydraulics that if a stream flows through a gradually diverging pipe the initial velocity head is gradually converted into pressure without appreciable loss.

To apply this principle to the centrifugal pump, the manufacturers of the turbine surround the impeller with stationary vanes, called diffusion vanes. These vanes are so arranged that they receive the water as it leaves the impeller, without shock, and conduct it by gradually diverging passages into a vortex chamber of volute casing. This type of pump is especially adapted for service under conditions of uniform flow at constant pressure, for the angle which the inner tips of the diffusion vanes make with the tangents to the discharge circle is calculated exactly as in the case of the inlet vanes of a water turbine, that is, so that they shall be parallel to the path of the water as it leaves the impeller. As this angle changes with the speed, the angle that is correct for one speed is incorrect for any other. Where there is a great variance between the speed at which the pump operates and that for which the vanes were designed, they actually obstruct the discharge.

The strength of the turbine lies in the fact that it

combines lightness and high efficiency, at constant flow, its weakness in that its efficiency is not maintained under varying conditions.

The vortex chamber pump is efficient under varying conditions but is necessarily heavier than either the turbine or volute casing pump.

The volute casing pump maintains its efficiency over a wide range of conditions, but its efficiency is never as high as the best turbine or vortex chamber pumps. Either single or stage impellers may be operated with any type converter here discussed.

STAGE PUMPS.—Single impellers can operate efficiently against pressure equal to that caused by several hundred feet of head, but for practical reasons it is desirable that the head generated by a single impeller should not exceed 200 ft. When high heads are to be handled it is customary to mount two or more impellers on the same shaft within a casing so constructed that the water flows successively from the discharge of one impeller into the suction of the next. Such an arrangement is called a stage pump, and each impeller, or stage, raises the pressure an equal amount.

Single impeller pumps are generally balanced against end thrust by a double suction arrangement which causes half of the water to enter the impeller from each side. Stage pumps are balanced by arranging the impellers in pairs, so that the end thrust of one impeller is balanced by the equal and opposite end thrust of its mate.

FIRE PUMPS.—The use of centrifugal pumps for fire protection has been formally approved by the Fire Insurance Underwriters, who have issued speci-

fications covering the essential features of a pump of this type to cover their requirements.

THE CENTRIFUGAL PUMP MOUNTED ON CHASSIS.—It must be confessed that an entirely satisfactory centrifugal pump, for operation in connection with an internal combustion engine, and mounted on chassis, has not been developed to date. This, however, is not to be wondered at, as the successful operation of this type of pump requires very nice proportions, and adjustment, of speed and pitch of the impeller, graduation of diffusion vanes, and proportion of discharge pipe leading from impeller chamber. That there is great difficulty in getting the proportions just right may reasonably be inferred from the fact that 200 years elapsed between the first recorded attempt in this direction and the development of a practical working pump.

The principles involved justify the belief that the development of the centrifugal pump towards fire department requirements will not be materially aided by any invention on which patent rights might be secured. Hence there is little to encourage manufacturers in making expensive experiments, as competitors could take advantage of any knowledge acquired.

From all this it is apparent that there is little likelihood of the centrifugal pump being developed along lines suitable for fire department service until some community, or combination of communities, is induced to defray the expense of experiment.

To have a pump of this type, suitable for mounting upon chassis, tried out, in connection with the internal combustion engine, under direction of the

best engineering skill, should prove laudable enterprise for the I. A. F. E.

By way of assurance to those who may fear that past failures make further endeavor inexpedient, it may be suggested that certain fundamental principles appear to have been overlooked in these endeavors, which decreed their failure from the inception.

One group of experimenters appears to have proceeded on the theory that impellers might be connected to the shafts of high speed traction motor and motors driven at such speed as to operate impellers efficiently.

The other line of experiments were conducted by connecting the impeller shaft to the motor crank shaft by gears or sprocket chains, and thus driving the impeller at a higher rate of speed than the motor. The partial failure (for it is by no means a complete failure) of this latter attempt is largely due to the fact that this transmission of power made the pump bulky and heavy, hard to dispose in suitable position on the chassis, and necessitated a heavier transmission, which in turn demands heavier chassis and other parts. Transmitting the power through gears make necessary repairs incident to additional wear.

In explanation of the failure of experiments described as group one, it appears sufficient to point out that the impeller of a centrifugal pump of the size that can be conveniently carried on a truck frame must, in order to operate efficiently, make two revolutions to the one which an ordinary traction motor can safely make.

What seems to be wanting is a motor capable of

revolving with sufficient frequency to drive an impeller at speed great enough to insure efficient operation. This should not prove impossible of development with a many-cylinder, short-stroke motor.

There is no principle of mechanics opposed to the development of a pump of this type that will satisfactorily meet the requirements of fire service.

Viewed entirely from the domain of reason, it seems that such a pump capable of meeting the requirements could be assembled by connecting a high speed, short stroke motor to an impelleer of the greatest diameter that can be conveniently carried on a chassis, the pitch of the blades of such impeller being cast most favorably to slow motion.

Matters of design, however, will have to be determined by experiment. And these experiments may prove more expensive than manufacturers can reasonably be expected to undertake, in view of the poor requital which success would be likely to bring.

GEAR PUMPS

The gear pump is a modern development of rotary. It possesses, in addition to some admirable qualities, the defects of the rotary. The qualities of this pump that recommends it, are low first cost, lightness, compactness, reliability and low upkeep. Low efficiency, due principally to slippage, and great vibration, due to the necessary pounding of the water gears, constitute its most marked defects

At the present state of the development of pumps, for operation in connection with the type of internal combustion engines used on traction motors, the gear pump is less objectionable than the reciprocating or

centrifugal types. In other words, it is the most suitable pump for fire service now on the market. This, however, should be regarded as an indictment of the other types rather than an indorsement of the gear pump.

At best the gear pump is ill fitted for handling non-viscous liquids, such as water.

The gear pump has its proper field in operating on liquids of high viscosity, such as starch, paints, heavy oils, soap, etc., etc. Such liquids cannot be impelled rapidly, hence the centrifugal pump loses its prime advantage when operating on them, while they clog the valve passages of plunger pumps.

PRINCIPLES OF THE GEAR PUMP.—Although the gear pump operates in revolving fashion, and in this respect resembles the centrifugal pump, it is in reality a displacement pump. That is, it pushes the liquid slowly ahead, generating pressure immediately in the pump casing. In this latter respect it resembles the plunger pump.

It is likely that the gear pump will hold sway, in connection with the gas engine, until a motor is developed capable of revolving with sufficient rapidity to insure efficient operation of impellers connected directly to the crank shafts of motors, or until an impeller is designed that will operate efficiently at more moderate rates of speed than that at which the impeller of today operates, or until modifications on both sides bring their efficiency speeds closer together.

PRACTICE EXERCISES—PART I

(1) What is science?

(2) How does scientific knowledge differ from the knowledge we acquire as the result of experience?

(3) What is inertia?

(4) What is motion?

(5) What is momentum? How does momentum differ from motion?

(6) What is meant by "varies inversely"?

(7) Does the number of steps a man takes in walking a mile vary directly or inversely with the length of his steps?

(8) If the unit for measuring weight be 1 lb. and the unit for the measurement of motion 1 ft. per second, what is the momentum of cannon ball weighing 500 lbs. and moving 500 ft. per second?

(9) A boat weighing 4 tons is moving at the rate of 5 miles per hour, another weighing 2 tons is moving at the rate of 10 miles per hour. How do their momenta compare?

(10) A boat is rowed at the rate of 4 miles per hour directly across a stream flowing at the rate of two miles per hour. What velocity of motion has the boat? If the river is a mile wide, how far does the boat move in crossing it?

(11) Why is it more difficult to throw a man when he stands with his feet apart than when his feet are close together?

(12) Why can a child walk more easily with a cane than without?

(13) Why is it more difficult to upset a wagon

loaded with stone than one loaded with hay?

(14) A body moves at a uniform velocity of 10 miles per hour for 10 hours. Over how great a distance does it move?

(15) While a train is moving at a uniform rate of 40 miles per hour a man walks from the rear toward the front. At what velocity, or rate of motion does the man move? If the man walks 4 miles per hour from the front towards the rear, what is his rate of motion?

(16) A ship weighing 10,000 tons is moving at a rate of 20 miles per hour, while an ice-berg weighing 1,000,000 tons is moving at a rate of a mile an hour; what are their relative momenta? (As 200,000 is to 250,000.)

(17) Is it possible to have motion without momentum?

(18) Is it possible to have momentum without motion?

(19) What is force? What effect has force upon a body against which it is applied?

(20) What is reaction?

(21) How may action be distinguished from reaction?

(22) Where is the center of mass of a body?

(23) If the beams and rounds of a 35-rung ladder were respectively of corresponding and uniform weight, where would its center of gravity lie?

(24) Where would the center of gravity of a similarly constructed 34-rung ladder lie?

(25) How may the center of weight of a ladder be determined experimentally?

(26) What is stability?

(27) Why is it that a ground rest ladder will not

stand unless the upper end is rested against a support, while a ladder erected upon the turn table of a truck will stand?

(28) Why is it more difficult to upset a water-tower than a hook and ladder truck?

(29) Why is a steamer engine more likely to upset in turning a corner than a gasoline pumper?

(30) How far from the perpendicular will an unsupported wall lean before it topples over?

(31) Why is it that walls of buildings do not always fall when they lean so far over as to carry the center of mass outside a line perpendicular to the base?

(32) Can objections be taken to the statement that the higher a body is carried the less stability it possesses? If so, what are the exceptions? If there are no exceptions, show why?

(33) Which has the greater stability, a hose wagon with a chemical tank carried above the driver's seat, or one without such a tank? Why?

MACHINES

(34) What is a machine?

(35) How many kinds of simple machines do you know about? Name them?

(36) What are the principles involved in those machines?

(37) Are the principles involved in any of those machines employed by firemen in the performance of their work?

(38) Do machines create force? If so explain how. If not of what use are they?

(39) What is a lever?

(40) Name 10 distinct operations in which firemen employ lever principles in the performance of their work.

(41) In what simple machines are lever principles involved?

(42) How many classes of simple levers are there?

(43) Describe a compound lever.

(44) Are compound levers employed by firemen? If so, for what purposes? If not, why not?

(45) What is meant by an arm of a lever? What is the power arm? What is the weight arm?

(46) State the mechanical advantage of the lever.

(47) Is a bent lever more powerful than a straight lever of equal length?

(48) State the relative positions of the power, the fulcrum, and the weight in a lever of the first class. In a lever of the second class. In a lever of the third class.

(49) With what class of lever, of given length, will a stated power lift the greatest weight?

(50) With which of the three classes of simple levers can a weight be moved the greatest distance, provided the levers are of equal length?

(51) In what simple machines are lever principles applied?

(52) What is a fulcrum?

(53) With a lever of the first class 8 feet long and having its fulcrum one foot from the weight end, what weight could be lifted by applying a force of 180 lbs. at the end of the power arm?

(54) A man weighing 180 lbs. wishes to raise a weight of 1,000 lbs., using a 30 ft. ladder as a lever of the first class: (a) What is the greatest distance from the weight that he could place the fulcrum? (b) What is the advantage of placing the fulcrum far from the weight end? (c) What is the advantage of planting the fulcrum close to the weight?

(55) A 30 ft. ladder is used as a lever of the first class in a floor having a height of 12 ft. If the fulcrum be placed 4 ft. from the weight end, how far can a weight be moved? 30:12::4:?. 1.6 ft. Ans.

(56) Why is it necessary to butt a light 25 ft. ladder when a 15 ft. iron ladder many times as heavy can be raised without being butted?

(57) If two men grasp a 35 ft. ladder 17½ ft. from the top, what weight does each man lift in order to raise the ladder? Provided the ladder weighs 170 lbs.

(58) If the men grasp the ladder 15 ft. from the top, what weight does each man lift?

(59) If the men grasp the ladder 15 ft. from the butted end what weight do both men lift?

$$P : W :: WA : PA$$

$$P = \frac{170 \times 17\frac{1}{2}}{15} \quad \text{Ans. 198.4 lbs.}$$

(60) In raising a 35 ft. ladder weighing 180 lbs. the points at which the hands of the men touch the ladder are 7 ft. 1 in. from the ground: (a) At what point in the process of lifting the ladder do the men sustain the greatest weight? (b) What is the greatest weight which they sustain?

Ans. (a) At the time when the hands of the men come in contact with the ladder at a point 10 ft. from its base. At that time the quotient obtained by dividing, the product of the weight multiplied by weight arm, by the power arm is greatest. Ans. (b) Throughout the raising of the ladder the weight arm continues to the horizontal distance from middle point of the ladder to a perpendicular at its base. Hence, the weight arm at the time in question is 12.4 ft., and the formula P :W : :WA :PA becomes P :180 : : 12.4 :10. Ans. 223.2 lbs.

(61) What weight do the men lift if they grasp the ladder at the end distant from where it is butted?

(62) What weight do the men lift if they grasp the 14th round from the top?

(63) A 30 ft. ladder weighing 4 lbs. to the running foot is lifted by a man who grasps the ladder 12 ft. from the top? (a) What weight does the man lift in order to raise the ladder? (b) What weight would the man be compelled to lift if he grasped the ladder 12 ft. from the butted end? (c) What is the greatest weight this man would sustain if the point where his hand supported the ladder at any given time was 6 ft. 8 in. from the ground? (d) What is

the greatest weight he would have to sustain?

(64) What mechanical principle is involved in the wheel and axle?

(65) What mechanical advantage is derived from an application of the wheel and axle?

(66) If a wheel has a diameter of 6 ft. and an axle a diameter of 6 in., what weight suspended from a cable wound on axle will a power of 100 lbs. support? (Disregard friction.)

(67) Where the principle of the wheel and axle is applied in the operation of extending the fiy of a hook and ladder truck, what sort of contrivance is utilized in lieu of a wheel?

(68) If the drum upon which the cable employed in extending the fly of an extension ladder is wound upon a drum 5 inches in diameter and the webs of the crank handles are 15 inches long, and ladder weighs 750 lbs., what weight must be applied to each of two such crank handles in order to move the fly? (Disregard friction.)

(68a) The inner tube of a water-tower weighs 1,250 lbs. What force must be applied to crank handles 20 inches long to move the tube, provided the drum upon which the cable is wound is 6 inches in diameter? (Disregard friction.)

(69) With a tower having a weight equal to that in question 68 but having crank handles 15 inches long and having the power transmitted through gears, there being 24 teeth in the drum shaft gear and 12 teeth in the crank shaft gear, what force applied to crank handles will move the tube?

(70) The middle section of a 3-piece ladder is 1,200 lbs. and the upper section 600 lbs. The drum upon which the hoisting cable is wound is 4 inches in

diameter. (a) With crank handles 18 inches long on the end of the drum shaft, what force would be necessary in order to extend the ladder? (b) If the drum were 9 inches in diameter and the power transmitted through gears, there being 30 teeth in the drum shaft gear and 12 teeth in the crank shaft gear, what power would it be necessary to apply to crank handles 15 inches long in order to extend the fly?

(71) Why does an increase in the diameter of the drum upon which a cable is wound necessitate (other things being unaltered) an increase in the power that must be applied in order to extend a ladder's fly section?

(72) The fly of a two-piece ladder weighs 600 lbs. while the mid and upper sections of a three-piece ladder weighs 1,800 lbs. The first is extended by crank handles connecting directly to the drum shaft. In the second case the power is transmitted through cog gears, the crank shaft gear having 9 teeth. How many teeth will be required in the drum shaft cog gear in order that the same power may be necessary to extend the ladders in each case, the drum shafts being of equal diameter? (Disregard friction and effect of the manner in which the cables of the 3-piece ladder are utilized for the transmission of the power.)

(73) What effect, if any, has it on the power necessary to extend a 3-piece ladder that the cables which hoist the upper section pass over the top of the middle section and are secured to the top of the bed ladder?

(74) In what manner could cables be employed so that a 3-piece ladder might be extended by the expenditure of a smaller amount of power?

(75) Could the mechanism for extending the upper sections of a 3-piece ladder be so connected that such ladders could be extended by power generated in the motor?

(76) Are there any objections to such mechanism being connected in such manner that ladders might be extended by power furnished by driving motors of apparatus?

(77) Discuss the relative merits of 2-piece and 3-piece ladders.

(78) Which of the 2 or 3-piece ladder is best suited for companies serving in (a) sections where private residences predominate, (b) tenement house sections, (c) hotel, theatre and department store sections, (d) manufacturing and commercial districts, (e) financial and office building districts?

(80). What are the merits and demerits of springs for raising: (a) Two-piece ladders? (b) Three-piece ladders? (c) Water towers?

(81) What are the objections to coupling the raising devices of aerial ladders to the driving motors of trucks?

(82) Discuss the relative merits of hydraulic and spring raising devices for water towers.

(83) The bed ladder of a hook and ladder truck is 41 ft. 6 in. with 1 ft. 6 in. on the side of the bearing shaft (fulcrum), on which the raising power is applied: (a) How far from the top is the center of gravity of the entire ladder? (b) How far from the top is the center of gravity of the weight section of the ladder? (c) How long is the weight arm, in contemplation of applying the lever principle to computing the power necessary to raise such a ladder?

(84) The bed ladder of a truck weighs 12 lbs. to the running foot, and the fly ladder 8 lbs. When the ladders are down they measure 47 ft., the power arm being 2 ft. What power is required to raise such a ladder? P:W::WA:PA.

$$P = \frac{W \times WA}{PA} = \frac{900 \times 22\frac{1}{2}}{2} = 10{,}125.$$

(85) The mast, the inner tube and fittings of a water tower have a weight equivalent to 40 lbs. to the running foot, uniformly distributed, is 40 ft. from the fulcrum to the top of tower, and has a power arm 2 ft long. (a) What power is necessary to raise the tower? (b) If the water cylinders were 9 inches in diameter, what pressure would be necessary on the hydrant or engine to raise the tower? (c) With 90 lbs. available on hydrants, what area of the cylinders would it be necessary to provide in order that the tower might be raised? (d) What would be the diameter of those cylinders?

Ans.: (a) 16,000 lbs. (b) 126 lbs. (c) 89 sq. in. (d) 10.7 in. (Friction is disregarded in those answers.)

(86) With height of tower the same as (85), how far from the fulcrum would the center of gravity be if the foot nearest fulcrum weighed 54 lbs., and the graduation of weight were uniform, the topmost foot weighing 38 lbs. Ans. 18.34 ft.

(87) Under the conditions stated in (86), what power would be required to raise the tower? Ans. 14,672 lbs.

(88) The inner tube of a water tower weighs 1,000 lbs. The cables by which it is hoisted are wound upon a drum 8 inches in diameter. There are

two crank handles each 16 inches long. Power is transmitted through gears, the drum shaft gear having twice as many teeth as the crank shaft gear. (a) What power must be applied to each crank handle in order to extend the tube? (b) When the tube is filled with water what force is necessary in order to start the tube upwards, the tube being 40 ft. long and 5 inches in diameter? (c) When the inner tube is hoisted a distance of 30 ft., what force is necessary in order to continue it upon its upward course? (d) What allowance should be made for friction in cases of this kind? (e) If a stream were in operation would it require more power to extend the tube? (f) Explain the reasons why the operation of stream would render greater power necessary?

(89) If the ladder described in question (84) was equipped with two crank handles 18 in. long and a system of cogs and gears so arranged that each complete turn of the crank handles moved the yoke end of the power arm 2 inches, what power would it be necessary to apply to the crank handles in order to raise the ladder from its bed?

(90) What principle of simple mechanics is involved in the screw?

(91) Which has the greater theoretical efficiency, the lever or the screw?

(92) If the ladder described in (84) had 18 in. crank handles and was raised by screws with a 2 in. pitch, what power would it be necessary to apply to the crank handles in order to raise the ladder?

(93) Where is the center of gravity of a hook and ladder truck as it stands in quarters?

(94) In what manner and to what extent is the

center of gravity altered by raising the aerial ladder to a vertical position? By extending the fly while the bed ladder is in a vertical position?

(95) What effect has it upon the center of gravity of the apparatus to swing the turn table while the ladder is in a vertical position?

(96) A two-piece ladder of ordinary dimensions, weight and general construction, has its aerial ladder raised and fly extended. To what angle from the vertical can such a ladder be lowered in a line at right angles to the frame without endangering the stability of the apparatus? Write your estimate for comparison with the results obtained by computation.

(97) Which of a two or a three-piece ladder can be lowered farthest from the vertical without endangering the stability of the apparatus?

(98) The bed and fly ladders of a hook and ladder truck are each 40 ft. long. The former is 20 and the latter 12 lbs. to the running foot. The whole apparatus weighs 13,000 lbs. To what angle from the vertical may such a ladder be safely lowered when the fly is extended 30 ft.

(99) What causes reactions (back pressure) when stream is in operation?

(100) What are the factors that determine the amount of reaction due to the discharge of a stream?

(101) Why is it easier to hold a line operating with a ½ in. tip than when operating with a 1¼ in. nozzle?

(102) There is pressure of 50 lbs. per square inch on a 1 in. nozzle: (a) To what weight in lbs. is the reaction equivalent? (b) Does it seem to one direct-

ing a stream of this kind that the reaction is greater than this? Explain.

(103) There is 70 lbs. pressure on $1\frac{1}{2}$ inch nozzle: (a) What is the total reaction? (b) How many men are required to properly operate a stream of this kind? Proper operation includes moving the line while stream is going and continuing the work for hours.

(104) With a 2 in. nozzle and 100 lbs. pressure, what is the reaction?

(105) A 35 ft. ladder weighing 160 lbs. is erected with its butt 9 ft. from the base of a perpendicular wall: (a) With what force does the upper end press against the wall? (b) If a man weighing 180 lbs. stands at a point half way up the ladder, what force would the upper end exert against the wall? (c) A man weighing 180 lbs. stands 10 ft. from the top. What force will be exerted against the wall by the upper end?

(106) What effect would it have upon the stability of the ladder considered in (105) if the butt were pulled farther away from the wall?

(107) How does it affect the force with which the top of a ladder rests against a wall to operate a stream from it in the manner in which streams are usually operated from ladders?

(108) The stream considered in (103) was operated 21 ft. from the butt of the ladder considered in (105), while a man weighing 180 lbs. stood $3\frac{1}{2}$ ft. below the point of operation. (a) With what force would the top of the ladder rest against the wall? (b) Would it be reasonably safe to operate such a stream from a ladder of the dimensions specified placed as stated?

(109) A 35 ft. ladder weighing 140 lbs. is placed with its butt 8 ft. from the wall against which the top rests. One man weighing 160 lbs. stands 22 ft. from the base of the ladder, another man of equal weight stands 7 ft. below him. A 1½ inch stream of 60 lbs. pressure is operated 10 ft. from the top of this ladder. What force does the top of this ladder exert against the wall while the stream is in operation?

(110) Where a ground rest ladder is placed against the wall of a building: (a) What angle should the ladder make with the wall against which it rests? (b) How far from the wall should the butt of a 35 ft. ladder be placed? (c) How far the near wheel of a 75 ft. extension ladder truck?

(111) In placing a ladder against the wall of a building, should the purpose for which it is to be used be taken into consideration when determining the angle at which it is permitted to rest?

(112) A water-tower is in operation with its inner tube fully extended. (a) Is there any danger of the tower upsetting? (b) Under such circumstances, which of a horse or motor tracted tower has the greater stability?

(113) The reaction due to the discharge of a stream from a water-tower nozzle causes a stress at the point where the inner tube passes through the shell. At what angle to the mast is the stream directed when this stress is greatest?

(114) With an inner tube 40 ft. long extended 33 ft. beyond the outer shell, the lower inner tube guide being 6 ft. from the bushing at the top of the shell. What stress is on the tube at the point where it passes through the shell, provided a 2-inch nozzle

at a pressure of 80 lbs. per square inch is used and the stream discharged at right angles to the mast. Ans. 1,413 lbs.

(115) Is there any danger of this force bending the tube of a tower? Give reasons.

(116) If the tower considered in (114) extends to a height of 64 ft. above the street level, and has a wheel spread of 8 ft., what force do the wheels distant from the building exert against the ground in addition to that due to weight? Ans. 4,016 lbs.

(117) Since the tower is no heavier with the stream in operation than when shut off, where is the additional weight derived from?

(118) How may potential energy be distinguished from kinetic energy?

(119) Show a condition of fire service under which water possesses: (a) Potential energy. (b) Kinetic energy. (c) Both potential and kinetic energy.

(120) Make clear 3 sets of circumstances under which water possesses great kinetic but little or no potential energy.

(121) State the merits and demerits for fire service of (a) The steam engine. (b) The internal combustion engine. (c) The reciprocating pump in connection with the steam engine. In connection with the internal combustion engine. (d) The rotary or gear pump in connection with the steam engine. In connection with the internal combustion engine. (e) The centrifugal pump in connection with: (1) Reciprocating steam engine. (2) Turbine driven steam engine. (3) Internal combustion engine. (4) Electric motors.

(122) What modifications seem necessary in the

construction of the internal combustion engine in order to adopt it for service with the centrifugal pump?

(123) Describe the internal construction of the centrifugal pump and explain the purpose of each of its parts.

(124) Show wherein the principles involved in moving water by means of a centrifugal pump differ from the principles involved in moving water by means of a reciprocating pump.

(125) In what particulars do gear pumps operate upon the same principles as reciprocating pumps?

(126) In what particulars do gear pumps operate upon the same principle as the centrifugal pumps?

(127) What type pump is best adapted for fire service in connection with internal combustion engines? State reasons.

PREFACE OF PART II

HYDRAULICS.—Hydraulics has been the subject of discussion amongst firemen for many years. It was first introduced as a purely practical matter, so that fire officers would not be guilty of gross errors in the number of lines stretched, the length of stretches, etc.

That firemen have not heretofore made gratifying progress in their study of the scientific features of that subject is not astonishing, nor need they feel in the slightest degree abashed at the modesty of their success in that direction.

The branches of hydraulics that are of especial interest to firemen are: (1) That which has to do with the resistance which water encounters in flowing through pipes. (2) The carrying distance of streams discharged from pipes at known pressures.

It seems that the second phase of the subject has never been scientifically inquired into, while the first has been investigated, experimented with, discussed, and written about, to a greater extent than any other subject in hydraulics.

The present state of our knowledge on the phase of the subject that has to do with frictional resistance may best be shown by quotations. Those quotations are from the most eminent authorities on the subject.

QUOTATIONS.—Writing in 1875 Lord Rayleigh said, "There is no part of hydrodynamics more puzzling to the student than that which treats of the resistance which flowing fluid encounters."

Writing in 1916 on the subject of fluid resistance, Horace Lamb, Professor of Mathematics at the Victoria University, Manchester, England, said on page 664 of the 4th edition of his work on Hydrodynamics, "That although the subject is important in many practical questions, and that although it has been studied with renewed vigor in recent years, yet our knowledge of it is mainly emphirical."

Lord Kelvin, speaking of friction in a general way, says: "According to the approximate knowledge we have from experiments, those forces are independent of velocity when due to friction of solids but are simply proportional to the velocities when due to fluid viscosity."

And he continues: "From all this it appears that the resistance due to viscosity varies as the viscosity, and that the total resistance encountered by a viscous liquid (water) flowing through a pipe may be expressed by the formula: $R=V+V^2$ with constants depending upon the diameter of the pipe." This was one of the early statements that led up to the doctrine that the resistance varies as the square of the velocity, a theory which as you shall see as we proceed is completely exploded.

DEVELOPMENT OF THE THEORY THAT THE FRICTION INCREASED AS THE SQUARE OF THE VELOCITY.—At an early date in the studies of the laws of motion it was found that the velocity of a freely falling body varied as the square root of the distance it had fallen and that the energy (kinetic) of which it was possessed varied as the distance it had fallen. When students first came to inquire into the resistance which water flowing in pipes encountered, it was observed

that the resistance increased more rapidly than the velocity and it appears that, for a time, this resistance was thought to come under the same rules that applied to falling bodies. That the forces acting upon a falling body and that encountered by water flowing in pipes rises from entirely different sources appears to have been lost sight of for a time.

From later experiments it began gradually to be seen that the resistance did not increase as the square of the velocity. Brief quotations will be given to show how that theory came to be finally dropped.

The first authoritative contradiction of the theory that we have been able to find is attributed to Professor Young, who wrote in 1808, "I began by examining the velocity of flow of water discharged from pipes of different diameters, and under different degrees of pressure, and found that the friction could not be represented by any single power of the velocity, although it frequently approached to the proportion of that power, of which the exponent is 1.8, but that it appeared to consist of two parts, the one varying simply as the velocity, the other as the square of the velocity.

The proportion of these parts to each other must, however, be considered as different in pipes of different diameters, the first being less perceptible in very large pipes, and in rivers, but becoming greater than the second in very small tubes. While the proportion of the second was of course greater as the internal diameter of the pipe increased."

There has been a vast amount of discussion upon the findings of Professor Young, but the reasonable

conclusion to arrive at as a result of such discussion may well be conveyed in the words of the greatest hydrodynamist of the race, Hermann Van Helmholtz.

Writing as late as 1894 Helmholtz said: "Such great difference between what actually takes place and the deductions from theoretical analysis hitherto accepted *must cause physicists to regard the hydrodynamical equations as a practically very imperfect approximation of the truth.*

The cause of this discrepancy might be supposed to lie in the internal friction of the liquid, although the divers strange and saltatory irregularities which everyone has encountered who has experimented upon the motion of fluids can in no wise be accounted for by the continuous and uniform action of friction."

From the time that Professor Young disclosed his findings, many others experimented upon the subject, but the result of their conclusions only adds to the confusion into which the subject seems to have fallen.

In 1884, Professor Osborne Reynolds, R. I., announced the results of a series of tests in which he had induced a colored fluid into the stream. By this means Reynolds found that at very low rates of flow the particles of water followed straight lines, but that after a certain velocity was reached, the straight line flow became broken and the particles of water dashed wildly about. The point at which the rectilinear motion becomes broken, he called and it has become known as, the critical point, and flows below the velocity at which the right line for-

mation is broken are said to be below the critical velocity.

Professor Reynolds says on this subject: "So long as the mean velocity over the cross-section falls below a certain limit, depending on the radius of the pipe the flow is smooth, but after the critical velocity is reached the rectilinear regime definitely breaks down and the motion becomes wildly irregular, and the tube appears to be filled with interlacing and constantly varying streams, crossing and recrossing the pipe."

VELOCITY AT WHICH THE CRITICAL POINT IS REACHED.—The velocity at which the critical point is reached depends to such an extent upon such circumstances as the internal diameter and the smoothness of the interior of the pipe, that to attempt to follow authorities upon the subject would only add to the confusion in which the whole subject is involved.

To this extent, however, authorities are in agreement: (1) The smaller the internal diameter of a pipe, the higher the velocity at which the critical point is reached, (2) The rougher the surface over which the water flows, the lower the velocity at which the critical point is reached. (3) The velocity at which the critical point is reached is less than any with which hydraulic engineers have to deal as a practical matter.

The velocities with which water flows in hose streams are much greater than the lowest with which hydraulic engineers have to deal; hence flows below the critical point cannot enter directly into their calculations.

But unless it be understood that at low rates of flow the friction increases less rapidly than at higher rates, and that the change in the relation between the increase in velocity and increase in friction takes place at a definite point, and not gradually, it would be impossible to develop an equation that would agree even approximately with facts observed empirically and the reasoning out of the subject.

FRICTION INCREASES RAPIDLY AFTER THE TURBULENT FLOW COMMENCES.—On this subject Professor Reynolds has this to say: "Simultaneous with the change in the character of the motion there is a change in the relation between the pressure (gradient) and the mean velocity. So long as the rectilinear character is maintained the gradient varies as the change in velocity, but when the irregular flow has set in the gradient increases rapidly, in many cases, apparently as the square of the change in velocity, more or less approximately.

This increase in resistance is no doubt due to the action of the eddies in continually bringing fresh fluid, moving with considerable relative velocity close up to the boundry and thus increasing the distortion rate greatly beyond what it would obtain in regular laminar (smooth flow) motion."

In Perry's applied mechanics this statement may be found: "Water flowing in a certain pipe at velocities 1, 2, 3, etc., inches per second has a friction proportional to 1, 2, 3, etc. Whereas at velocities 1, 2, 3, etc., yards per second the friction is proportional to 1, 4, 9, etc. At small velocities 3 times the speed means 3 times the friction, while

at great velocities 3 times the speed means 9 times th friction."

Although the statement just quoted is only approximately correct, calculations made upon it are helpful, and equations based upon it are used by many hydraulic engineers.

FRICTIONAL RESISTANCE AND VELOCITY.—G. E. Russell, Assistant Professor of Civil gineering, Massachusetts Institute of Technology, has this to say relative to the varying relations which frictional resistance bears to the velocity of flow: "For any pipe the amount of frictional resistance must be some function of the velocity. We have so far assumed it to vary as the square of the velocity, but experimental work has shown that in general the value of the exponent is somewhat less than 2."

Professor Russell appears to conclude that for a short period after the critical point is passed the increase in frictional resistance increases as the square of the increase in velocity, but that for a wide range the exponent 1.72 gave results closely approximating those obtained from tests.

"The subject of friction loss, and its relation to the velocity of flow, and other matters that govern its proportions, such as the diameter of the pipe and the nature of the inner surface have been the subject of more experiment and writing than any other in the field of hydraulics. In spite of which fact, we have little exact knowledge of the law, and our formula, which expresses it, gives only approximate results. Even temperature enters into the problem to add to its complexity."

"From the many experiments that have been made, we do know that the amount of frictional resistance is:

"(1) Independent of the pressure in the pipe.

"(2) Proportional to the extent of the friction surface.

"(3) And varies with the velocity of the flow and is nearly proportional to the second power of the velocity, if the latter be above the critical point, if the velocity be below the critical the resistance varies as the first power of the velocity."

SINUOUS MOTION.—When water flows with a velocity exceeding the critical, the water is said to have a sinuous motion. The expression is illustrative of what takes place in river and open streams, and probably in large, rough lined pipes at comparatively low velocities of flow. But it is hardly descriptive of flow formation in small pipes, particularly at high velocities, such as takes place in fire service hose lines. The expression is well established and must be accepted as designating the flow formation after the smooth line flow has been broken up.

Authorities are agreed that when the turbulent (sinuous) flow sets in, the particles of water dash wildly about, crossing and recrossing the pipe.

Professor Russell compares the flow of a stream to the movement of a body of soldiers, and the laws of hydraulics to a drill book, and shows that while smooth flow continues the particles move forward without interrupting each other, but that as soon as the turbulent flow commences they impede each other's progress as do the individuals of a body of

troops in rout. And he concludes that the enemy that causes the confusion in the water is the lack of uniformity of pressure in the different parts of the stream.

Another writer likens the appearance of the stream, after the turbulent flow has set in, to a cloud of feathers blown about in the wind.

DISCUSSION.—From the discussion just completed the student should be able to form a mental picture of what takes place within a pipe in which water if flowing, and he should also be able to appreciate to some extent the complexity of the subject.

The following is presented as a summary of the conclusions that may reasonably be taken from the attitude of writers generally.

(1) That the principal factor in determining the friction is the velocity of flow.

(2) That the next most important factor is the size of the pipe.

(3) That the character of the surface over which the water flows is a factor, but not a very important one.

(4) That, as the more authoritative writers agree with Helmholtz, in that the hydrodynamical equation is but a very imperfect approximation, and as there is considerable variety in the conclusions arrived at by writers of less authority, it seems advisable to approach the subject from a somewhat different point of view from that from which it has been approached heretofore.

COMPUTING FRICTION LOSS.—The method of computing friction loss heretofore used is based

upon an equation derived from observation of various tests, made under varying conditions, and adopted because by its (the equation's) use results were obtained which more closely approximated the net results of the varying tests than could be obtained by the use of any other equation.

This method is well adapted to the solution of problems of the character with which hydraulic engineers are confronted, for when working such problems engineers have access to tables and formulas.

The method does not meet the needs of the fire service, as the friction loss at any rate of flow is computed from the friction loss at some other rate of flow in the same size of pipe, making it necessary for the student fireman to commit to memory the friction loss for some rate of flow in every size of pipe with which he might be called upon to deal, or commit to memory other data equally taxing to the recollection.

To meet the reasonable demands of the fire service in a satisfactory manner it seems necessary to develop a formula by which the friction loss in pounds per square inch for any stated length of hose line, can be computed when the diameter of the hose (or its equivalent) and the rate of flow, as the gallons per minute (or its equivalent) may be known or given.

The manner in which any important conclusion is arrived at is a proper matter for consideration in connection with the study of the subject to which the conclusion applies.

With the recognition for the need of a new formula came a realization that any deviation from

the logical in its pursuit would lead away from that object. Mindful of that fact, an attempt was made to reason out the cause, or causes, of friction where water flows through hose lines.

The reasoning which led to finding the formula here used is based upon the laws of motion.

From these laws it is learned that a body in motion will continue in motion with constant velocity, i.e., there would be no resistance were it not acted upon by some outside force. Hence, the cause of the friction that retards water, flowing in pipes, cannot be in the water itself, and thence must of necessity be due to the only thing with which it comes in contact, i.e., the hose through which it flows.

That water can be forced through pipes is due to the fact that the molecules of that liquid may easily be caused to change their relative positions. Some force is necessary to cause them to change their positions, hence it is apparent that while the hose is the primary cause of friction its amount is to some extent, if not wholly, determined by a property of the water itself. The property of water that determines the amount of friction is known as viscosity.

It is generally agreed that water does not slide along the surface of a pipe or other container, but that motion is accomplished by the particles rolling past each other. If this be so, the particles most distant from the material composing the inner surface of a container move more rapidly than do those which are closer to it. From this it may be seen that the greater the diameter of a pipe the less rapidly the particles will change their relative positions in maintaining a given average velocity of flow. And as the amount of friction depends upon the rapidity

with which the particles pass each other, the greater the diameter of a pipe the less the friction encountered in maintaining a given velocity flow.

All authoritative writers on hydraulics are agreed that the greater the diameter of a pipe the less the friction for stated velocity of flow. They differ, however, in the relative efficiency which they attribute to larger pipes. (1) Some maintain that the efficiency varies as the wetted surface, i.e., the circumference. (2) Others that the variation is as the area of cross-section. Each of these theories was, in turn, made the basis of computation tests, and it was found that, insofar as hose lines are concerned, neither one was, even approximately, correct.

If the circumference or diameter of a pipe be doubled, the cross-section area is increased four times. Thus, according to method (2), the larger hose would show a relative efficiency over the smaller hose twice as great as that shown by method (1).

In the course of making mathematical trials in conformity with theories (1), (2), it was observed that the results obtained by tests were always between, and approximately equidistant, from the results obtained by such trials.

From the consistency with which the results of tests fell between those obtained mathematically by following the theories just stated, it was surmised that a formula, based in part upon a first power of the dimension (i.e., the circumference, diameter or radius) and in part upon the second power (i.e., the area of cross-section, square of the diameter or square of radius) might be developed that would

prove in agreement with results obtained empirically.

This surmise proved to be substantially correct, for by a formula, based in part upon the first and in part upon the second power of the dimensions, results closely approximating those found by tests were obtained.

The fact that it was found expedient to go to the fourth power of the radius for one of the factors in one of the formulas finally adopted is not to be taken as evidence of our having abandoned the belief that the whole can be worked out from applications of the first and second power.

After many trials, the results of which were continually approaching nearer to those obtained by tests, two distinct formulas were finally adopted. The first is intended as a ready method for the solution of such problems as would be likely to be encountered at civil service examinations. This formula is written: $F = \frac{V}{D} + \left(\frac{1}{2}\frac{V}{D}\right)^2$, in which F represents the fritcion loss in pounds per square inch for each 100 ft. of hose in line, V the velocity of flow in feet per second, and D the diameter of the hose in inches.

The results obtained by the use of this formula will be found substantially correct at flows of from 200 to 500 gallons per minute in 2½-inch hose, 300 to 800 in 3-inch and 400 to 1,000 in 3½-inch. It is not recommended for rates of flow less than the minimum or greater than the maximum stated.

The second formula is written:

$$F = \frac{V}{D} + \left[.54 \left(\frac{V}{D} - \frac{D}{R^4} \right) \right]^2$$

In this formula F, V and D represent the same values as in the preceding formula, and R represents the radius of the pipe in inches.

FORMULA STATED IN WORDS.—In words the formula: $F = \frac{V}{D} + \left(\frac{\frac{1}{2}V}{D} \right)^2$ may be stated as:

The friction loss in pounds per square inch for each 100 ft. of hose in line is equal to the quotient of the velocity of flow in feet per second by the diameter of the hose in inches + the square of ½ the quotient of the velocity of flow in feet per second by the diameter of the hose in inches.

Formula: $F = \frac{V^1}{D} + \left[.54 \left(\frac{V}{D} - \frac{D}{R^4} \right) \right]^2$ may be stated in words thus:

The loss of pressure due to friction in pounds per square inch for each 100 feet of hose in line is equal to the quotient obtained by dividing the velocity of flow in feet per second by the diameter of the hose in inches + the square of .54 times the quotient of the velocity of flow in feet per second by the diameter of the hose in inches — the quotient of the diameter of the hose in inches by the fourth power of the radius of the hose in inches.

The results obtained by working out the latter formula are in very close agreement with the results of tests and there is no substantial disagreement at any rate of flow or in any size of pipe with which

firemen have to deal, except such as may be satisfactorily explained on other grounds than defect in formula.

VELOCITY.—To persons of limited mathematical education studying this subject the suggestion is offered that they thoroughly master the method for finding the velocity of flow before attempting to work out the formulas.

So important is this considered, that, although the method of finding the velocity of flow is fully shown in the body of the work, it is deemed advisable to briefly state it here.

The velocity of flow in inches per second is equal to the product obtained by multiplying the number of gallons flowing per second by the length of the line in inches that will contain one gallon. This product should then be stated in feet, for feet per second is the form in which velocity is generally stated.

The length of a line in inches that will contain one gallon may be found by dividing 231, the number of cubic inches in one gallon, by the cross-sectional area of the hose in square inches.

With these facts well in hand there should be very little difficulty experienced in negotiating the formulas.

ALTITUDE TO WHICH STREAMS RISE AND DISTANCE THEY CARRY.—A search for a statement, based upon reason, relative to the carrying distance of streams proved futile.

An inquiry into the extent to which the principles involved in finding the range of projectiles might prove applicable in efforts to find the carrying dis-

tance of streams, leads to the conclusion that the same principles apply in so far as the theoretical range is involved, and that the rules may be applied in the same manner, in computing the altitude streams attain, but that it would be an error to apply them in the same manner in computing the horizontal range of streams.

These conclusions are based upon the following facts:

(1) The laws of motion and of gravitation apply equally to solids and liquids, and these are the laws that govern the range of projectiles.

(2) The range of a propelled liquid varies from the theoretical much more than does that of a solid. This is on account of the greater surface which the liquid offers to the resistance of the air after it becomes broken up into drops or small masses.

The method for finding the range of projectiles involves one fact that does not apply to streams. That fact, and its significance, may be seen from the following: The path of a projectile is a parabola, which if reproduced upon a surface and bent at its highest point, so as to lay one section over the other, both would correspond throughout their entire length, and form one line; and the distance from the point of propulsion to a perpendicular at the highest point to which a projectile rises is equal to the distance from that point to where the projectile strikes, provided the striking point is on an equal level with that of propulsion.

When a stream becomes broken the amount of surface that becomes exposed to the air is much greater than that exposed when the stream maintained its compact form. Hence the arc constitut-

ing the path formed by the disassociated particles of water has a much shorter horizontal dimension than that traversed by the ascending column.

It is, perhaps, more difficult to follow the reasoning upon which the process of finding the range of streams is based than it is to follow the reasoning on any subject heretofore dealt with.

It has been attempted to present the subject in such manner that it may be mastered by persons of good natural reasoning powers, but who do not possess sufficient mathematical knowledge to enable them to pursue the study as such intricate subjects are usually set forth.

There are three factors involved in determining the theoretical range and the direction of motion of projectiles:

(1) The velocity of propulsion. (2) The law of gravity. (3) The angle of direction. (2) being always the same, the factors that must be known or given, in order that the range may be determined, are the velocity of propulsion and the angle of direction.

HOW THE ALTITUDE TO WHICH A PROJECTILE RISES IS COMPUTED.—The formula for finding the height to which a body projected vertically upward, at a stated velocity, rises is written: $h = \frac{1}{2}gt^2$, in which h represents the height in feet, g 32.16 feet (the acceleration due to gravity) and t the time in seconds during which the body is in flight.

Since the value of g is constant and that of t unknown, it is necessary to first find the value of t. If V be made to represent the velocity in feet per

second at which the projectile is propelled, the value of t may be found from the formula: $t = \frac{V}{g}$.

The key to all such problems is to find the value of t. That is, the time the projectile is ascending. This known, the height (the value of h in the formula) is easily determined, for it is the product obtained by multiplying ½g by the square of t.

While the foregoing is the method generally used, the same result may be obtained (where the initial velocity and the time are known) by multiplying ½ the initial velocity by the time. For the average velocity is always equal to ½ the greatest velocity, whether such greatest velocity is the initial velocity of an ascending or the final velocity of a descending body.

The source from which those formulas, as well as all others used herein, are derived is fully shown in the body of the work, and the purpose of showing the more important factors is in order to preclude the possibility of their purpose being obscured during the process of tracing them to that source.

In so far as finding the altitude is involved, the same principles apply to streams and to solid projectiles.

HOW THE HORIZONTAL RANGE OF A STREAM MAY BE FOUND.—To find the horizontal range of a stream, it is first necessary to find the horizontal velocity of propulsion in feet per second, and second the time in seconds of the stream's flight up to the point where it reaches its

maximum altitude. Then the range may be found by multiplying the horizontal velocity in feet per second by the time in seconds of the ascending portion of the flight. The product thus obtained is the horizontal range of stream in feet.

PART II

HYDRAULICS APPLIED TO FIRE FIGHTING

Section I

WATER AT REST

Properties of a Perfect Fluid

FLUID.—A perfect fluid is a substance that offers no resistance to change of form unless the deformation is accompanied by a change of volume.

Our interest is in that branch of the mechanics of fluids that relates to water.

As arranged in text books the subject of hydraulics is subdivided into hydrostatics, relating to water at rest; hydrokinetics, relating to water in motion; and hydrodynamics, which relates to the forces exerted by fluids in motion, and the energy available from them.

GAS AND LIQUID.—Liquids possess the property of cohesion, which causes the particles to cling together, form in drops and remain in equilibrium when the surface is exposed. One result of this is that numerous experiments may be made with liquids while in that condition in which they are found in nature.

Gases tend to expand indefinitely and as a result they must be confined for the purpose of experiment.

Gases are highly elastic, while the elasticity of liquid is very slight. It requires a pressure of approximately 294,000 lbs. per square inch to diminish the volume of water 1 per cent, so that its property of compressibility, i.e. elasticity, may be disregarded except for experimental purposes, or as furnishing a theory explanatory of phenomena otherwise inexplicable.

IDEAL FLUID.—The fluid of science offers no resistance to change of form, and presumedly would flow through pipes without offering or encountering any resistance, and, therefore, without friction loss.

VISCOSITY OF LIQUIDS.—Every known liquid possesses some degree of viscosity. It is the property of viscosity that renders it necessary to apply force to liquid in order to change its form. This property of liquids is defined in a variety of ways. Some define it as the tendency to resist shear. The greater the shearing force a liquid will resist the greater the viscosity it is said to have. By others it is referred to as stickiness, while a modern English writer calls it Treacliness. A substance like gasoline that flows freely has slight viscosity, while cold molasses is highly viscous.

With phenomena that are attributable to viscosity we shall be much concerned, and this property will be more fully discussed under the head of "flow of water."

DENSITY OF WATER.—In hydrodynamical calculations, even where the fluid under consideration is not water, the standard unit of weight used is the weight of one cubic foot of water at 54 degrees

F. Water attains its maximum density at 39 degrees F., and at that temperature a cubic foot of water weighs 62.42 lbs. From this the weight diminishes as the temperature increases until at 212 degrees F. the weight is 59.57 lbs. At about 54 degrees F. the weight is 62.4 lbs. and this is the accepted standard. In hydraulic calculations this constant is represented by a letter. In this work, however, algebraic formulas will be used only to present the ideas in concrete form and in each such case the particular function of characters will be stated.

PRESSURE OF WATER

TRANSMISSION OF PRESSURE THROUGH WATER.—It is a fundamental principle of hydrostatics that when a fluid at rest has a pressure applied to any portion of its surface, that pressure is transmitted undiminished through all parts of the fluid and to all parts of the enclosing surface, and that the force so exerted on the surface presses at right angles to such surface.

This is a very important principle and many mechanical devices, such as the hydraulic jack, hydraulic press, hydraulic crane, etc., represent applications of it.

We, however, are interested in a somewhat different application of the principle from that utilized in mechanical devices and need to have it illustrated in a different manner.

If a pipe one-eighth of an inch in diameter be connected to a tank in a cellar, extended upwards to the fortieth floor of a building and filled with water, the pressure on the tank would be exactly the same

as if it (the tank) were connected to an eight-inch standpipe of the same height.

ATMOSPHERIC PRESSURE and PRESSURE ON SUBMERGED SURFACES.

RELATION OF PRESSURE TO DEPTH.—The free surface of a liquid at rest in an open vessel or tank, has the same curvature as the surface of the earth and is regarded as perfectly level. As the atmosphere pressure is practically constant, and therefore the pressure at one point compensates for the pressure at any other, the surface pressure of a liquid is considered as zero and when dealing with pressure on submerged surfaces only the weight of the water is considered.

Gages and other appliances for measuring pressure are so constructed that the zero point is at atmospheric pressure and when it becomes necessary to measure pressures below that exerted by the atmosphere a, so called, vacuum gage is used.

The pressure at any point in a liquid due to its own weight is directly proportional to the depth of this point below the free upper surface. Hence the pressure per square inch on a submerged surface is equal to the weight of a column having a cross-section of one square inch and a height equal to the depth of the designated submerged point below the upper free surface.

The pressure per square foot on a surface submerged to any depth may be determined by multiplying the height in feet of the column of water above the submerged surface by 62.4, the weight of a cubic foot of water. The pressure per square inch may be obtained by dividing this product by 144.

Example: The submerged surface being 100 feet below the free upper surface. $62.4 \times 100 = 6240$ lbs.

This represents the weight of a column of water one foot square and 100 feet in height, and therefore the pressure per square foot on the submerged surface.

If this product be divided by 144, the number of square inches in a square foot, the quotient obtained is 43.3 the weight of a column of water one inch square and 100 feet in height, and, therefore, the pressure per square inch for a head of 100 feet.

Thus the pressure per square inch is shown in the formula $\dfrac{62.4h}{144}$ in which h represents the height in feet of the column of water.

.433, that is the quotient obtained by dividing 43.3 by one hundred, represents the weight in pounds of a column of water one foot in height and having a cross-section of one square inch. This is the factor used for finding the pressure when the head in feet is known.

100 divided by 43.4 gives a quotient of 2.30 which represents the height in feet of a column of water having a cross-sectional area of 1 sq. in. and a weight or pressure of one pound. This is the factor used when the pressure is given and it is desired to determine the head in feet.

STRENGTH OF PIPES UNDER INTERNAL PRESSURE

STRENGTH OF HOSE LINES.—In the case of

pipes flowing full, the pressure of the liquid produces stress on the walls of the pipe.

When this stress exceeds the tensile strength (hoop stress) of the material of which the pipe is constructed the pipe bursts.

The question of the most suitable hose for fire service cannot be settled satisfactorily until firemen are capable of preparing their own specifications. This they may do when they master that branch of the science of mechanics which deals with the stress, or strain, on pipes subjected to internal pressure.

Assume that before the couplings are put on a length of hose a ring one inch in length is cut from the hose, and subjected to strain on an expansion ring.

The object of this test is to determine the pressure which the hose will withstand. As the testing ring is expanded it registers the stress to which it is subjected. This is equal to the strain applied to the band of hose.

We now wish to know how the pressure that will subject the hose to a strain equal to that shown on the testing ring may be determined.

Suppose the hose to be 3 inches in diameter and subjected to a pressure of 100 lbs. per square inch. Under those conditions a ring of the hose one inch in length, as it has an area of 9.5 square inches, will sustain a total pressure of 100×9.5 or 950 lbs.

It is not unreasonable that men studying this branch of mechanics without the aid of an instructor should regard this as the strain to which each part of the band of hose is subjected.

An instructor, however, might explain it in this way: Consider the band of hose as cut so that it is

a straight strip. If this strip be put in a straight pull testing machine it will be necessary to secure one end before any strain can be applied to it, and there will be as much strain on the secured end as on the end attached to the testing machine, and yet only the strain on the machine side will register, as that represents the strain at any one point of the strip. The same principle applies where pressure is exerted on inside of a circular pipe. One side may be regarded as holding. Therefore, the tearing strain is not what would be obtained by multiplying the pressure in pounds per square inch by the circumference in inches.

As a matter of pure reasoning the strain would appear to be equal to what might be obtained by multiplying the pressure in pounds per square inch by ¼ the circumference in inches. For if the strain on one half be supposed to hold while only the pull on the other half is registered it will be seen that the strain is applied to two points.

The rule adopted is that the strain on any point of longitudinal dimension is equal to the pressure in pounds per square inch multiplied by the diameter in inches.

Thus the strain in the case we are considering would be 100×3 or 300 lbs. on each inch in the length of the line.

As ¼ the circumference of a 3-inch pipe is only 2.355 the actual strain would appear in this case to be only 235 lbs., as against the 300 according to the rule. But the rule is well recognized and was, no doubt, arrived at as a result of careful inquiry into the question.

EQUILIBRIUM OF FLUIDS IN CONTACT.

HEAD INVERSELY PROPORTIONAL TO THE SPECIFIC WEIGHT.—It is commonly said that water will seek its level. This means that if two receptacles containing water are connected by a tube near their bottoms water will flow through this pipe until the surface level of the water in each receptacle is at an equal distance from the surface of the earth in a line dropped perpendicular to their surfaces. This is true only where the water in each tank is of the same specific gravity, that is, of the same weight per unit of measure.

If a tank containing water at a temperature of 211 F. degrees be connected near the bottom by a small tube to a similar tank containing water below 40 degrees F. the surface of the water in the former will stand at a height of 62.4 inches if the height of the water in the latter tank be 59.7 inches. This is due to the fact that water at maximum density is about 5% heavier than water at the boiling point.

If, while the water is standing thus, salt be dissolved in the cold water, the surface in the cold water tank will sink while the surface level in the hot water tank will rise. Showing that it is the weight of the fluid that determines the level at which it shall stand.

If a tank containing mercury be connected near the bottom with one containing cold water the depth of the water will be 13½ times as great as the depth of the mercury. This is because mercury is 13½ times as heavy, per unit of measure, as water.

In like manner if water be placed, to a height of 34 feet, in an enclosed tank and the air above its sur-

face exhausted, this column of water will exactly balance a column of air reaching to the top of the atmosphere.

The height in feet of a column of any fluid that a column of water of known height will sustain may be determined by dividing the height in feet of the water column by the specific gravity of the other fluid.

Example: A column of water 100 ft. in height will sustain a column of mercury equal to 100 ÷ 13.6 or 7.35 ft.

The height in feet of a column of any fluid that a column of any fluid of known height will sustain may be determined by multiplying the height in feet of the column by the specific gravity of the fluid.

Example: A column of air 1000 feet in height will sustain a column of water equal to 1000 × .001-293 or 1.293 ft.

EQUILIBRIUM OF FLOATING BODIES

BUOYANCY.—When a solid body, such as a ship, floats in water partly submerged, it displaces an amount of water equal in weight to itself.

If the floating solid be a piece of timber, nails may be driven into it until the timber just floats, with the smallest possible portion of it above the surface. It may be said that this piece of timber now displaces a volume of water equal to its own volume. If one or more additional nails be driven into it the timber will sink beneath the surface of the water, but will not necessarily sink to the bottom. It will be remembered that earlier in this work it was said that water has slight elasticity and was therefore capable of being compressed. A re-

sult of this is that water at depths beneath the surface being subjected to the weight of the water above it, is more dense, that is, occupies less space per unit of weight, than the water at or near the surface.

Therefore the greater the depth to which a solid sinks in water the greater the density of the water which it encounters.

The superior buoyancy effects which water beneath the surface furnishes to solids floating in it is not proportional to the greater pressure on the surface of the solid, but is proportional to the greater density of the water subjected to the weight.

If the density were proportional to the weight on the surface of the floating solid, marble, granite and glass would float at a depth of 85 ft. and iron and steel at a depth of 258½ ft.

As a matter of fact, the superior density of water at depths beneath the surface is but slightly in excess of what it is at and near the surface.

It may be thought that all this has but little to do with the branch of hydraulics especially applicable to fire fighting. It is stated here because a knowledge of the principles involved are necessary to a comprehensive study of the subject.

DETERMINATION OF SPECIFIC WEIGHT BY EXPERIMENT

SPECIFIC WEIGHT.—The specific weight of a body may be determined by first weighing it in air and then weighing it in water. The specific weight of a body is equal to its weight in air divided by its loss of weight in water.

A solid body heavier than water may easily be weighed in water by suspending the body in the water holding the weighing apparatus above the surface.

TO FIND THE SPECIFIC WEIGHT OF A SOLID LIGHTER THAN WATER.—Fasten to it another body heavy enough to sink it in water. Find the loss of weight for the combined mass when weighed in water. Do the same for the heavy body. Subtract the loss sustained when the heavy body is weighed in water from the loss sustained when the combined mass is weighed in water. Divide the weight of the lighter body when weighed in air by this difference and the quotient will be specific weight, or density, of the given body.

EXAMPLES.—When the solid is heavier than water.—A block of granite having a volume of one cubic foot, is found by test to weigh in air 170 lbs. When submerged the block was found to weigh 107.6 lbs. Thus there was a loss of 62.4 lbs. Now, $170 \div 62.4 = 2.71$, which represents the specific gravity of the particular grade of granite from which the block was hewn.

When the solid is lighter than water.—A block of wood, having a volume of one cubic foot, weighs in air 48.4 lbs. This block of wood may be submerged by attaching to it a block of metal weighing 120 lbs. The weight in air of both bodies amounts to $120 + 48.4$ or 168.4 lbs. Assume that the block of metal has a volume of one-fourth of one cubic foot. When the test is made in water there will be a loss of weight of 78 lbs., while when the block of metal is weighed in water the loss will be 15.6 lbs. By sub-

traction we get $78 - 15.6 = 62.4$ and $48 \div 62.4 = .77$, which represents the specific weight of this particular kind of wood.

In dealing with problems of this kind it is necessary either that tests be made, or that volumes be assumed or stated.

PRINCIPLE APPLIED TO AN ALLOY.—Where a body is an alloy or mixture of two different substances whose specific weights are known, the relative proportions of each substance contained in the mixture may be determined by an application of this principle. The more of the heavier substance the mixture contains the less will be its volume per unit of weight, the less the loss when weighed in water, therefore the smaller the divisor and the higher the quotient, which represents the specific weight of the substance.

This principle was first applied to alloys by Archimedes, a Greek mathematician, in about 250 B. C., in order to solve a practical problem.

Heiro, King of Syracuse, had furnished a quantity of gold to a smith to be made into a crown. When the crown was returned it was found to be of full weight, but it was suspected that the smith had kept out a considerable amount of gold and substituted an equal weight of silver. To test the truth of this suspicion Archimedes first balanced the crown against an equal weight of gold and then immersed both in water, where the gold outweighed the crown, proving the suspicion to be well founded.

ZERO BUOYANCY.—When a solid body lies against the bottom of a vessel containing water,

fitting the bottom so closely that no water can get under it, its buoyancy is said to be zero.

In order to move such a solid body away from the bottom it is necessary to exert a pulling force sufficient to lift the solid and a weight equal to that of a column of water having a cross-sectional area equal to that of the submerged body and of a height amounting to the depth of such submerged body below the upper surface of the water.

In other words, the force necessary to pull such a body free is the same as would be necessary to lift the body itself and the column of water vertically above it.

Section II

FLOW OF WATER

Flow of Water from Tanks

STREAM LINE.—In the case of a flowing liquid, the path followed by any particle of the liquid in its course is called a stream line. Specifically, if a deep tank be filled with water and a small opening made in its side near the bottom, the stream lines starting far apart near the surface become crowded more closely together as the orifice is neared.

From this it may be seen that the particles of water approach the orifice obliquely and from different directions, and not, as is the case with fire streams, in a line with the direction of the stream after it passes the orifice. This direction of flow, coupled with the momentum with which the particles advance, tend to carry them across the opening. This results in the stream lines continuing to crowd more closely even after the opening is passed, with the resulting contraction of the stream known as the "Contraction of Jet."

For a sharp-edged orifice with a complete contraction of jet the actual discharge is about .62 of the theoretical or ideal discharge.

In a smooth cone nozzle with a gradually tapering bore there is no measurable converging of the stream after passing the end of the pipe. This is shown in the fact that the best shaped nozzles have a coefficient of discharge as high as .97 as against the .62 for the sharp-edged orifice. It may also be observed from the use of the Pitot tube, for the pressure registered by that instrument is at its highest when

the opening of the tube is in line with the end of the nozzle. While when the Pitot gage is used to test the discharge from a sharp-edged orifice, it is found that considerably higher pressure is recorded when the tube is held away from the opening a distance equal to ½ the diameter of the opening.

In connection with this phase of the subject much is written about what is called a "Liquid Vein," which it is said the stream lines form. Summed up, however, it means, in addition to the conditions just considered, that the stream lines take a funnel-like-form, and that the velocity of flow is greatest where the cross-section of this funnel is least. The result of this is that although the velocity of water near the top of a tank may be almost infinitely slight, yet the velocity with which it approaches the opening will be considerable if the tank is deep. The momentum which water thus acquires before reaching an orifice accounts for the high velocity with which it passes through—a velocity far in excess of what it would be if all the water in a tank approached the opening at the same rate of motion.

VELOCITY HEAD.—This subject is extensively discussed in text books dealing with hydraulics, but it has to do, for the most part, with the question of potential energy lost and kinetic energy gained, as water in descending from higher to lower levels acquires momentum, in accounting for the difference between ideal and actual discharges and in working out of formula whereby the actual discharge may be ascertained where the conditions are known.

With the extent to which the potential energy lost is available in kinetic energy gained we are not

especially interested at this time. In dealing with the discharge from nozzles the coefficients given by Mr. John R. Freeman are used, for the reason that they are approved by Fire Department Officials generally, and presumedly, by Civil Service Commissions in various cities.

Hydraulic engineers generally express the opinion that Mr. Freeman's coefficients are too high, but this is a question which firemen can properly enter into only when they make their own tests and compute the findings for themselves.

In view of the conditions just considered, we may deal with the subject of velocity head as if the ideal and actual were identical.

An orifice in the bottom of a tank has a head equal to the number of feet in a perpendicular line from the orifice to the upper surface of the water. If the flow be unimpeded and the area of the tank is so large in comparison to that of the opening that sides of the tank cause no friction the velocity head may be said, for our purpose, to be equal to the actual head. And when an orifice in the bottom of such a tank is open the water flows with a head equal to the number of feet in the depth of the water in the tank.

Where one tank discharges into another through a short pipe, both ends of which are submerged, the velocity head is equal to the difference in feet between the level of the water in the two tanks.

The term velocity head is properly applicable only to the flow of water past a given point at which there is a measurable decrease in pressure or a measurable decrease in the velocity of flow.

IDEAL VELOCITY FLOW.—The relation between head and flow is known as Torricelli's Theorem and is written $V = \sqrt{2gh}$. in which V stands for velocity in ft. per second. Expressed in words, it says that the ideal velocity of flow under a static head, h, is the same as would be acquired by a solid body falling in a vacuum from a height equal to the depth of the opening below the free surface of the water.

The reasonableness of the theory is apparent, for if a bar of iron were dropped down a vertical pipe, it would descend at the same speed as a ball, and by the time the upper end of the bar had reached the point from which the lower end started it would be traveling at identical velocity and altitude with a ball which started on equal terms of time and position with the upper end of the bar.

This principle was discovered about 1640 by an Italian mathematician named Torricelli. It is supposed to be governed by the same principles that apply to the acceleration due to gravity. This latter being a law of nature is invariable.

The law is stated thus: The velocity of a freely falling body at the end of any second of its descent is equal to 32.16 ft. multiplied by the number of seconds it has been falling. Consequently, at the end of one second the falling body has acquired a velocity of 32.16 ft. and this is the value of g in Torricelli's Theorem.

ACTUAL VELOCITY FLOW.—The viscosity of a liquid, as well as the form and dimensions of an opening may modify the discharge considerably. The coefficient of viscosity of water is stated to be .97,

but it is apparent that the higher the coefficient of discharge the lower the coefficient of viscosity and, therefore, that .97 cannot be more than a loose approximation.

With the coefficient of viscosity, however, we are not especially interested, as our pressures being taken at the nozzle the imperfection of flow due to this property of water is accounted for in the friction loss.

VELOCITY COMPUTED NUMERICALLY.—Bearing in mind that V represents velocity, h height in feet, and that g has a constant value of 32.16, Torricelli's Theorem becomes $V = \sqrt{2 \times 32.16h}$ or $\sqrt{64.32h}$.

EXAMPLE.—To find the velocity of flow for a head of 100 ft. $64.32 \times 100 = 6432$ and $\sqrt{6432}$ is 80.2, which represents the velocity of flow in feet per second for a head of 100 feet.

The formula is the same whatever the height, except that the value of h varies.

EQUIVALENT OF HEAD.—The head may be either the actual height in feet of the water on the orifice; or if the vessel is closed and the pressure is produced by steam, compressed air, or as in fire service, by some form of pumping device, the effective head is the height to which the given pressure would sustain a column of water.

The height of the water column that any given pressure will sustain may be determined by calculating the weight of a column of water 1 ft. high and 1 sq. in. in cross-section, from which it is found that 1 ft. head equals 0.434 lb. pressure per square inch,

and as $1 \div .434 = 2.304$ one lb. in pressure is equivalent to a head of 2.304 ft.

Whenever the pressure is given and it is desired to learn the head in feet this may be done by multiplying the pressure in lbs. per sq. inch by 2.3.

VELOCITY DETERMINED FROM PRESSURE.—To determine the velocity of flow when the pressure is known, multiply pressure in lbs. per square inch by 2.3 which will give the value of h in Torricelli's formula.

EXAMPLE.—The pressure registered on the Pitot gage being 100 lbs., $100 \times 2.3 = 230$. Therefore, the value of h in this problem is 230, and the formula becomes $V = \sqrt{64.32 \times 230}$ or $\sqrt{14793.6}$ which is 121.6, the velocity of flow at a pressure of 100 lbs. per square inch.

PRINCIPLES, ON WHICH THE VELOCITY DUE TO HEAD ARE BASED.—This paragraph is for the information of men wishing to know just how the methods considered in the three immediately preceding paragraphs have been developed. It is not considered as essential to a sufficient understanding of the whole.

As before stated, the velocity of discharge, as determined by head or pressure, is based on the acceleration due to gravity.

In working out the conclusions reached, a fact, found by experiment, is stated in two ways and by equating the formula derived therefrom the method given has been obtained.

(1) Experiments show that the velocity of a freely falling body at the end of any second of its descent

is equal to 32.16 multiplied by the number of seconds it has been falling.

(2) The distance traversed by a freely falling body during any number of seconds is equal to 16.08 multiplied by the square of the number of seconds it has been falling.

If in (1) V, is the velocity in feet per second, g, 32.16, and t time in seconds, the proposition may be stated thus $V = gt.$ and $t = \frac{V}{g}$ also $t = \frac{v^2}{g^2}$ If h, is the height in feet (2) may be stated $h = \frac{1}{2}gt^2$ Substituting the values $h = \frac{1}{2}g \times \frac{v^2}{g^2}$ or its equivalent

$$h = \frac{V^2}{2g} \quad \text{Hence } V = \sqrt{2gh.}$$

DISCHARGE COMPUTED FROM THE VELOCITY OF FLOW.—In computing the discharge from fire nozzles there are three factors that must be included in the computation.

(1) Area of the nozzle. (2) Velocity of flow. (3) Time, or duration of flow.

In any problem the area or the diameter of the nozzle must be given, and also the head in feet or the pressure in lbs. per square inch. Where the time or volume is not stated it is customary to compute by the number of cubic feet or the number of gallons per minute.

The pressure, or head, and the area of nozzle being known, the discharge may be found by (1). Dividing 231, the number of cubic inches in one gallon, by

the area of the nozzle in square inches, the quotient obtained will be the length of the stream in inches per gallon. (2) Divide the quotient thus obtained by 12 and the second quotient will be the length of the stream in feet per gallon. (3) Divide the velocity of flow ($V - \sqrt{2gh}$) in feet per second by the latter quotient, and the third quotient, which will be thus obtained, will constitute the number of gallons flowing per second, which multiplied by 60 gives the flow in gallons per minute.

Example.—Area of nozzle 3.1416.

Pressure, 100 lbs. per square inch.

$100 \times 2.3 = 230$, $230 \times 64.32 = 14793.6$.

$\sqrt{14793.6}$ 121.6 The velocity of flow in feet per second. The velocity of flow being now known. $231 \div 3.1416 = 73.5$, $73.5 \div 12 = 6.125$, $121.6 \div 6.125 = 19.9$, the number of gallons flow per second, which multiplied by 60 gives the flow per min. $19.9 \times 60 = 1194$ and this multiplied by the coefficient of discharge .997 gives 1189.

As the diameter of a nozzle having an area 3.1416 is 2 inches it will be seen that this result corresponds with the findings of Mr. Freeman.

The reason for putting the subject matter in the form here given is to make it possible for men to follow the reasoning upon which the velocity of flow and the volume of discharge are computed without undertaking the extensive mathematical course necessary to enable them to trace the principles through algebraic formula.

WHEN THE DIAMETER OF NOZZLE IS GIVEN.—Where the diameter of the nozzle is given a much simpler method for computing discharge has

been found. In words it may be stated thus: Square the diameter, multiply by the square root of the pressure and multiply the product by 29.7. In mathematical form it becomes $29.7D^2\sqrt{P}$, in which D represents the diameter of the nozzle in inches, and P the pressure in lbs. per square in. This method is subject to adverse criticism in that it is arbitrary, has no educational value outside of its especial purpose and must be remembered as a separate fact.

EFFECTIVE HEAD.—Where an orifice is in the bottom of a vessel, the head is of course the same at every point of the opening, but if the orifice is in the side of the vessel the head varies with the depth of opening. In case the depth of the opening is small the head may be assumed to be constant and equal to the distance of the center of orifice (if it be circular) from the free upper surface of the liquid.

From this it is apparent that for equal pressure the volume of flow is the same whether the discharge be downward, upward or horizontal.

FIRE NOZZLES.—From such tests as have so far been conducted it appears that the most efficient nozzle for fire service is the smooth cone nozzle having a uniform taper which results in a loss of diameter at the rate of one inch to each eight inches of nozzle length. Hence a nozzle 3″ by 1½″ should be 12″ long while a 2½″ by 1¼″ should have a length of 10″.

A nozzle with this range of taper is the most efficient, apparently, for the reason that it is the most abrupt taper that can be used without causing such contraction of the stream, after it passes out of the

nozzle, as to diminish the volume of flow. It has also been observed that where the stream contracts after leaving the nozzle the stream breaks sooner than where there has been no contraction. Where the taper is less the nozzle must be longer and there is friction loss for which there is not sufficient compensation.

KINETIC PRESSURE DISTINGUISHED FROM STATIC PRESSURE.

KINETIC PRESSURE IN A FLOWING LIQUID.—For a liquid at rest the normal pressure exerted by it on any bounding surface is called the hydrostatic pressure. If the liquid be in motion, however, the normal pressure it exerts on a bounding surface, whether on the walls of a pipe through which it is flowing, or on a liquid vein, it follows an entirely different law. This may be seen from the fact that when the water is static, as when a controlling nozzle is shut off, the pressure at any two points in the line is equal, while in the case of flowing water the pressure is found to vary as the cross-section of the line through which it is flowing.

There seems to be an impression in the minds of many who have had some experience with flowing water that when the water is forced through a pipe or nozzle of small diameter there is a choking of the stream and a consequent increase of pressure on the sides of the pipe. The contrary, however, is true, for when a liquid is at rest and exerting an equal pressure on all parts of the surrounding surface the whole of the liquid's power to perform work is in the form of potential energy. In order that the liquid

may flow, part of this energy must be dissipated, and part of the remainder is present in some other form than in pressure on the walls of the container. This second form of energy is called Kinetic pressure. The sum of the static pressure and of the kinetic pressure can be at most equal to what the static pressure was before the water began to flow. Therefore, flowing water cannot exert as much pressure on the walls of its container as does static water of equal head. And following out the reasoning of the subject, if flow diminishes the pressure on the surrounding surface the greater the velocity of flow the more the pressure is diminished.

That there is little pressure on the walls of a nozzle through which water is flowing at high velocity seems to be borne out by the fact that the stream continues after leaving the nozzle. For if there were much lateral pressure the stream would spread immediately on passing the end of the pipe, for it must be remembered that all matter follows the line of least resistance. Further evidence to the effect that there is little lateral pressure on a nozzle is found in the fact that when the tube of the Pitot gage is held in the stream after it has passed beyond the end of the nozzle the pressure recorded is as great as when it was held within the nozzle.

If the line of reasoning followed here be sound it appears that even before the water passes out of a nozzle practically the whole of the potential energy which it possessed in a static state is transformed into kinetic energy and can be measured only in that form.

VENTURI METER.—The rate of flow, in many

modern systems of water works, is controlled by a device which illustrates quite clearly the principles just considered. This contrivance is called a Venturi meter, and consists simply of two fustrums of conical tubes having their small ends connected by a short section of pipe of small diameter inserted in a line through which the flow is to be measured. If a pressure gage be inserted into the throat section of the meter and another on each side (of the meter) in the large section of pipe it will be found that the pressure recorded by the gages connected on the large sections of pipe is higher than the pressure on the one in the contracted section. That necessitates the water passing from an area of lower to one of higher lateral pressure. This apparent contradiction of natural law is accounted for by the fact that the kinetic pressure is not recorded on the pressure gages, and that there is much greater kinetic pressure in the throat section of the meter than in the sections where the pipe has larger diameter. The kinetic energy of flowing water may be measured by inserting a tube into the stream with its open end against the flow.

Section III

Flow of Water in Pipes and Hose Lines

LOSS OF PRESSURE DUE TO FRICTION.—The unsatisfactory condition of our knowledge on the subject of friction loss, with a statement of the reasons which appear to account for the uncertainty that exists will be found in the Preface.

In this part of the work discussion of causes, etc., is limited to what is essential to enable the student to work out the problems and to clearly understand the principles involved and the methods by which the conclusions are reached.

LIMITATIONS DUE TO INSUFFICIENT EMPIRICAL DATA.—The fact that there is insufficient reliable data on the friction encountered by water in flowing through large pipes at high velocity makes it impossible to say whether the formula given here shows the result in pipes of this class.

Tests made with 1½″ hose indicate that the friction loss in hose of that size is not as great as indicated by an application of this rule. This discrepancy may be accounted for by the fact that the nozzles used were not of the most efficient type.

IMPORTANCE OF USING ONLY THE MOST EFFICIENT TYPE OF NOZZLE.—Wherever discharge of nozzles or friction loss is computed from the area of the nozzle and the pressure, the utmost care should be taken that the nozzle used is of the highest possible efficiency, for a very slight defect in a nozzle materially affects the discharge.

The difficulty of getting reliable data on the subject of friction loss, and the importance of using only the proper kind of nozzle may be seen from the fact

that by merely changing nozzles, on the same stretch of hose, the computed friction loss showed an increase of 40% which involved a 20% increase in discharge. In that test the first nozzle used was only 80% efficient.

On the most careful measurements it was found that these nozzles had equal area of discharge, the only difference being that the taper of the least efficient one was slightly more abrupt than that of the other.

AMOUNT OF FRICTION DEPENDS UPON THE VELOCITY OF FLOW AND THE SIZE OF LINE.—A number of tests have been made to determine the loss of pressure due to friction where water flows through fire hose. From observations made at those tests data has been compiled, and from this data the following may be observed: (1) That the loss of pressure due to friction varies directly as the velocity of flow, and inversely as the size of the pipe. (2) That the increased loss of pressure due to friction resulting from increased velocity of flow follows a principle; and also that the decrease in loss, for any given rate of flow, as the size of the pipe increases, also follows a principle.

Anything that performs according to a principle may be brought within scope of applied mathematics, if the principle be understood.

For computing the extent to which friction loss is affected by an increase in the size of pipes two methods have been taught. Some writers state that the variation is inversely proportional to the circumference of the pipes (i.e. as the area of the wetted surface). Others hold that the friction varies as the

area of cross-section. The results obtained by one of these methods differ widely from that obtained by the other, as may be seen from the fact that area of cross-section increases twice as rapidly as does the circumference. It may also be noticed that the results obtained empirically fall about equidistant from those obtained by computing according to the two methods just stated.

From this it may be seen that the variation is not according to the wetted surface, nor yet according to the area of cross-section, but according to some numerical factor that may be obtained from the circumference and the area of cross-section. And this is what should in reason be expected, for it is the wetted surface that retards the flow and causes the friction while the greater the area the smaller the relative quantity of water which comes in contact with the retarding surface. Thus the area of cross-section and the wetted surface constitute the main, if not the only factors, that have to be considered in dealing with the question of friction relative loss in lines of different diameters.

HOW THE NUMERICAL FACTOR WHICH SHOWS THE RELATIVE FRICTION LOSS IN PIPES OF DIFFERENT SIZES, FOR ANY GIVEN VELOCITY OF FLOW, MAY BE FOUND.— (From the friction loss for a given velocity of flow, in any size of pipe, the factor for finding the friction loss, in any other size of pipe, for the same velocity of flow is shown in the formula:)

$$F = \frac{D \div D' + A \div A'}{2} = \text{factor}$$

In which F is the friction loss for each 100 ft. of hose in the line, D the diameteer of the larger pipe in inches, D′ the diameter of the smaller pipe in inches, A the cross-section area of the larger and A′ the cross section area of the smaller pipe in square inches.

In words the rule for finding the relative friction loss for any given velocity of flow may be stated thus: Divide the diameter of the larger pipe by the diameter of the smaller pipe, and the area of the larger by the area of the smaller pipe. By adding the two quotients and dividing by 2 the factor may be found. By dividing the friction loss in the smaller hose, at any velocity of flow, by this factor the friction loss in the larger hose, at the same velocity of flow, may be found.

In working out the example it will be remembered that the area of a 2½-inch line is 4.9 sq. in., that of a 3-inch line 7.07 sq. in., and that of a 3½-inch 9.6.

EXAMPLE.—With a flow of 200 gallons in 2½-inch hose there is a friction loss of 10.1 lbs. for each 100 ft. of hose in the line. At an equal velocity of flow, in 3-inch hose, there is a discharge of 290 gallons, and in 3½-inch hose 392 gallons. Reducing the factors in the formula above to their numerical values and first comparing the 2½ and 3-inch lines we get: $3 \div 2\frac{1}{2} = 1.2$, $7.07 \div 4.9 = 1.42$. Now $1.2 + 1.4 = 2.6$, and $2.6 \div 2 = 1.3$.

The friction loss in 2½-inch hose is 1.3 times as great as the friction loss in 3-inch hose for an equal velocity of flow, as may be seen from a comparison of the tables given in the end of the book and which

are based on experiments made by Mr. John R. Freeman.

Comparing the 2½-inch with the 3½-inch we find that: $3.5 \div 2.5 = 1.4$, $9.62 \div 4.9 = 1.92$. Now $1.4 + 1.92 = 3.3$ and $3.3 \div 2 = 1.65$.

The friction loss in 2½-inch hose is 1.65 times as great as the friction loss in 3½-inch hose for an equal velocity rate of flow.

If we divide 10.1, the friction loss per 100 ft. of 2½-inch hose, for a velocity of flow 13 ft. per second, by 1.3, we get 7.7, which is the friction loss in 3-inch hose for a like velocity of flow.

By dividing 10.1 by 1.65 we get 6, which accurately represents the friction loss in 3½-inch hose at a velocity flow of 13 ft. per second, for at that velocity there is a discharge of 392 gallons per minute.

RELATION BETWEEN FRICTION AND RATE OF FLOW IN PIPES OF DIFFERENT SIZES.—Where an equal volume of water flows through two pipes of different diameters the loss of pressure due to friction varies inversely as the area of cross-section.

When the friction loss for any rate of flow in any size of pipe is known the friction loss for an equal rate of flow in any other size of pipe may be found, by multiplying the friction loss in lbs. per square inch, for any given length of line, by the 5th power of the radius of the given pipe, and dividing the product by the 5th power of the radius of the pipe for which it is sought to find the friction loss.

EXAMPLES.—The friction loss in 2½-inch hose is known and it is desired to find the friction loss

for an equal rate of flow in 3 and 3½-inch hose. With a flow of 500 gallons per minute in 2½-inch hose there is a friction loss of 55 lbs. for each 100 feet of hose in the line.

The 5th power of the radius of 2½-inch is 2.975.
The 5th power of the radius of 3-inch is 7.6.
The 5th power of the radius of 3½-inch is 16.6.

55 × 2.975 = 163.6, 163.6 ÷ 7.6 = 21.3, which it may be seen from a comparison with the tables in the back of the book is the friction loss in 3-inch hose, 500 gallons flowing.

To find the friction loss in 3½-inch hose, 500 gallons flowing, divide 163.6 by 16.6 and the quotient will be found to be 9.8, which is .3 lb. greater than that shown in the tables.

By comparing the results, obtained by this method of computation, at a flow of 200 gallons it will be found that the variation is less than .1 lb., when the comparison is made between 2½-inch, 3-inch or 3½-inch hose. By this method we are able to compute the friction loss with considerable accuracy, for in no case does it vary from the results of the tests as much as 1 lb. per square inch for each 100 feet of hose in line.

LOSS OF PRESSURE DUE TO FRICTION FOUND FROM THE NUMBER OF GALLONS FLOWING AND THE DIAMETER OF THE PIPE.—The loss of pressure in pounds per square inch in any size of pipe at any rate of flow is represented in the formula: $F = \frac{V}{D} + \left(\frac{\frac{1}{2}V}{D}\right)^2$, in which F represents the loss of pressure in lbs. per

square inch for each 100 ft. of hose in line, V the velocity of flow in feet per second, and D the diameter of hose in inches.

To find the velocity of flow in feet per second: Multiply the number of gallons flowing per second by the length of line in feet that will contain one gallon and the product will be the velocity in feet per second.

The length of a line in feet that will contain one gallon may be found by dividing 231, the number of cubic inches in one gallon, by the area in square inches of the line, and the quotient by 12, the number of inches in a foot, and the second quotient will be the length in feet of the line that will contain one gallon.

LENGTH IN FEET OF A LINE THAT WILL CONTAIN ONE GALLON.—The cross-section area of $2\frac{1}{2}$-inch hose is 4.9 sq. in. $\frac{231}{4.9} = 47$, $\frac{47}{12} = 3.9$, which represents the length in feet of a $2\frac{1}{2}$-inch line that will contain one gallon.

The area of a 3-inch line is 7.07, $\frac{231}{7.07} = 32.5$, $\frac{32.5}{12} = 2.7$, which represents the length in feet of a 3-inch line that will contain one gallon.

The area of a $3\frac{1}{2}$-inch line is 9.6, and 2 ft. of such a line will contain one gallon.

The working-out of those problems may be shortened somewhat by dividing 231 by 12 times the area

of the line, or by other combinations of the numbers that do not disturb the fundamental values.

500 gallons flowing per minute in 2½-inch hose, the rate of flow per second is $\frac{500}{60}$ or 8.3 feet, and 8.3×3.9 is 32.4 feet, which is the velocity of flow in feet per second where 500 gallons flows per minute in 2½-inch hose.

The area of a 3-inch line is 7.07 and the length of 3-inch line that will contain one gallon 2.7 feet, and with 500 gallons per minute flowing the velocity of flow is 22.4 feet.

The area of a 3½-inch line is 9.6 sq. in., the length of a 3½-inch line that will contain one gallon 2 ft., and with 500 gallons per minute flowing the velocity in feet per second is 16.6 ft.

The velocity of flow in feet per second being known, we may substitute the values in the formula: $F = \frac{V}{D} + \left(\frac{\frac{1}{2}V}{D}\right)^2$, which may now be written, for 500 gallons flowing in 2½-inch hose:

$$F = \frac{32.4}{2.5} + \left(\frac{\frac{1}{2}32.4}{2.5}\right)^2$$

Working out the formula: $F = 13 + (6.5)^2 = 55.2$ lbs., the loss of pressure due to friction in 100 ft. of 2½-inch hose with a flow of 500 gallons per minute.

Substituting the values where 500 gallons flows per minute in 3-inch hose: $F = \frac{V}{D} + \left(\frac{\frac{1}{2}V}{D}\right)^2$ be-

comes $F = \frac{22.4}{3} + \left(\frac{\frac{1}{2}22.4}{3}\right)^2$.

Working out the formula: $F = 7.5 + (3.7)^2 = 21.2$ lbs., the loss of pressure due to friction in 100 ft. of 3-inch hose with a flow of 500 gallons per minute.

Substituting the values where 500 gallons per minute flows $3\frac{1}{2}$-inch hose $F = \frac{V}{D} + \left(\frac{\frac{1}{2}V}{D}\right)^2$ becomes $F = \frac{16.6}{3.5} + \left(\frac{8.3}{3.5}\right)^2$.

Working out the formula: $F = 4.7 + (2.3)^2 = 10$ lbs., the loss of pressure due to friction in 100 ft. of $3\frac{1}{2}$-inch hose with a flow of 500 gallons per minute.

The results obtained by this method show a greater friction loss at low velocities of flow than that found by tests, and it is not recommended for velocities in excess of 35 ft. per second. The velocity of flow in fire service is rarely less than 15 ft. per second or more than 35 ft. per second, and at rates of flow between these points the method is in substantial agreement with the results of tests.

At low velocities of flow the increase in friction loss for a given increase in velocity is not as great as after the critical velocity flow is passed. On account of this condition a formula that is substantially correct at low velocities of flow cannot be accurate at high velocities. The best that seems

possible at the present time is to develop a formula that will give substantially correct results over a wide range of velocities.

In working out a formula that would cover a wide range of velocity for hose of the size used in fire service a second formula has been developed. This formula gives substantially accurate results for any velocity flow for which there is authoritative empirical data. In this formula one factor more is used than in the one last considered. This additional factor may be regarded as a regulator which keeps down the numerical value of friction loss at low velocities of flow. From a scientific point of view there is an objection to this latter formula in that at very low rates of flow it shows a "minus friction," which is, of course, impossible. It seems, however, that for reasons which may be set forth later, nothing giving results closer to the facts can be found than that shown in the formula $F = \frac{V}{D} + \left(\frac{\frac{1}{2}V}{D}\right)^2$, unless by the development of a formula that will give at very low velocities of flow a "minus friction."

What may be designated as formula (2) is written: $F = \frac{V}{D} + \left[.54 \left(\frac{V}{D} - \frac{D}{R^4} \right) \right]^2$. At very low velocities of flow the value of $\frac{D}{R^4}$ is greater than

that of $\frac{V}{D} + .54\frac{V}{D}$, in which case there is a "minus friction." The method that is pursued in the development of this formula is to start the computed friction line below the zero of actual friction and in such a position that upon reaching the critical point it will correspond in position and direction with the line developed empirically.

DEVELOPMENT OF FORMULA (2).—In the development of this formula it was sought to give appropriate weight to every influence that is known to affect, in a measurable degree, the resistance which water encounters in flowing through hose lines. Cognizance is taken of the velocity of flow, area of cross section and diameter, and the factor $\frac{D}{R^4}$ is used to counteract the irregularity due to the change of direction of friction line after the velocity flow exceeds the critical point.

WORKING OUT THE FORMULA AT THE LOWEST VELOCITY OF FLOW OF WHICH THERE IS AUTHORITATIVE RECORD.—With 70 gallons per minute flowing in 2½-inch hose: 70 gallons per minute gives 1.14 gallons per second, and 1.14 multiplied by 3.9 (the length in feet of a 2½-inch line that will contain one gallon) equals 4.4, hence with 70 gallons flowing per minute in 2½-inch hose there is a velocity flow of 4.4 ft. per second.

The diameter of hose and velocity of flow being known, the formula:

$$F = \frac{V}{D} + \left[.54\left(\frac{V}{D} - \frac{D}{R^4}\right)\right]^2$$

may be written:

$$F = \frac{4.4}{2.5} + \left[.54\left(\frac{4.4}{2.5} - \frac{2.5}{1.25^4}\right)\right]^2$$

Working out the formula we get: $F = 1.7 + .54(1.7 - 1)^2$, $F = 1.7 + (.54 \times .7)^2 = 1.7 + .1 = 1.8$.

By working out this formula we find that the loss of pressure due to friction in 100 ft. of 2½-inch hose with a flow of 70 gallons per minute is 1.8 lbs.

WORKING OUT THE FORMULA AT THE HIGHEST VELOCITY FLOW OF WHICH THERE IS AUTHORITATIVE RECORD.—A flow of 1,100 per minute is equal to 18.33 gallons per second. 18.33 multiplied by 2.73 (the length in feet of a 3-inch line that will contain one gallon) equals 50, hence the value of V in the formula is 50. The value of V and D being known, the formula:

$$F = \frac{V}{D} + \left[.54\left(\frac{V}{D} - \frac{D}{R^4}\right)\right]^2$$ by substitution

of values becomes:

$$F = \frac{50}{3} + \left[.54\left(\frac{50}{3} - \frac{3}{5}\right)\right]^2 = 16.7 + [.54(16.7 - .6)]^2 = 16.7 + (.54 \times 16.1)^2$$

$F = 16.7 + 75.6 = 92.3$ lbs., which represents the loss of pressure due to friction in 100 ft. of 3-inch hose with a flow of 1,100 gallons per minute.

WORKING OUT THE FORMULA WITH 500

GALLONS FLOWING IN 2½-INCH HOSE.—With 500 gallons flowing per minute in 2½-inch hose there is a velocity of flow of 32.7 ft. per second. And as the value of D is 2½, and that of R 1¼, the formula: $F = \frac{V}{D} + \left[.54 \left(\frac{V}{D} - \frac{D}{R^4} \right) \right]^2$, may, by substituting values, be written $F = \frac{32.7}{2.5} + \left[.54 \left(\frac{32.7}{2.5} - \frac{2.5}{1.25^4} \right) \right]^2$, and by working out it becomes $F = 13.1 + \left[.54 \left(13.1 - \frac{2.5}{2.44} \right) \right]^2$. $F = 13.1 + [.54 \quad (13.1 - 1),]^2$, $F = 13.1 + (.54 \times 12.1)^2 = 13.1 + 42.6 = 55.7$.

WITH A FLOW OF 1,000 *GALLONS PER MINUTE IN* 3-*INCH HOSE.*—With a flow of 1,000 gallons per minute in 3-inch hose there is a velocity of flow of 45.4 per second. The value of D being 3, and of R 1.5, the formula

$$F = \frac{V}{D} + \left[.54 \left(\frac{V}{D} - \frac{D}{R^4} \right) \right]^2,$$ may by substituting values, be written.

$$F = \frac{45.4}{3} + \left[.54 \left(\frac{45.4}{3} - \frac{3}{1.5^4} \right) \right]^2,$$ and by working out we find that

$$F = 15.1 + \left[.54 \left(15.1 - \frac{3}{5} \right) \right]^2 = 15.1 +$$

$.54(15.1 - .6)^2$, $F = 15.1 + 61.23 = 76.33$.

WITH A FLOW OF 1,100 *GALLONS THROUGH* 3½-*INCH HOSE.*—With a flow of 1,100 galons through 3½-inch hose there is a velocity flow of 36.46 ft. per second. The value of D being 3½, and that of R 1¾, the formula: $F = \frac{V}{D} +$

$$\left[.54 \left(\frac{V}{D} - \frac{D}{R^4} \right) \right]^2$$

, may, by substituting values, be written

$$F = \frac{36.46}{3.5} + \left[.54 \left(\frac{36.46}{3.5} - \frac{3.5}{1.75^4} \right) \right]^2 = 10.5 +$$

$$\left[.54 \left(10.5 - \frac{3.5}{9} \right) \right]^2$$

, $F = 10.5 + [.54(10.5 - .4)]^2 = 10.5\ (.54 \times 10.1)^2$, $F = 10.5 + 29.75 = 40.25$.

COMPARISON OF COMPUTED FRICTION LOSS WITH THAT SHOWN BY TESTS.—From the tables compiled as a result of tests it may be seen that the loss of pressure due to friction with 500 gallons flowing per minute in 2½-inch hose is 55 lbs. per 100 ft. while that obtained by this method of computing is 55.7, and the loss according to the tests for 1,000 gallons flowing in 3-inch hose 76.5 while that obtained by this method is 76.33. With 1,100 gallons flowing in 3½-inch hose the tests show a loss

of 41 lbs. as against a loss of 40.25 as computed.

As the relations, between test findings and that obtained by this method, are even closer at velocities of flow, commonly required in fire service, and as at any velocity, relative to which we have data, the results are in substantial agreement, we are justified in proceeding with investigations as if this method were correct.

If, as is quite possible, it should develop that the actual friction loss in fire hose is greater than that shown in the tables now accepted, a formula, based upon the principles here adopted, may be worked out that will be in substantial agreement with the new findings.

EFFECT OF ROUGH SURFACE

The fallacy, in relation to the extent to which a slight unevenness, in the surface of a solid over which water flows, will affect the resistance, seems to have received its first stimulus from an opinion which formerly prevailed, to the effect that water in flowing through pipes slides along the surface of the container.

If water did slide along the surface of a pipe it is reasonable to suppose that a slight roughness in that surface would materially increase the friction, but if it does not slide on the surface particles of water fill slight depressions and the other particles roll over them without greatly disturbing the smoothness of flow. While the sliding theory prevailed every variation in resistance observed, and for which there was no other evident cause, was attributed to roughness of surface.

Since the experiments of Professor Russell and

the calculations of Professor Lamb and others have established beyond reasonable question that water does not slide along the surface of a solid, the causes of variations in frictional resistance are being more closely inquired into, and satisfactory reasons, apart from any roughness of surface, have been found in many cases formally attributed to that cause.

But even if there were no experiments or calculations on the subject it is difficult to see how it could be contended that water slides along a surface that remains wet after being set or hung in a perpendicular position.

The fallacy referred to seems to have received support from the observation of water flowing in open streams, rivers, canals, etc. But in such cases the conditions are altogether different, for the projections found in such channels cause counter currents which narrow the cross-section of flow, and by the counter direction of the water along the banks, make it necessary for the particles to pass each other at greater velocities than would be the case for the same volume of flow were it not for the counter currents.

IRON PIPE.—Another consideration that went to foster the error was based on experiences with iron pipe. The flow capacity of iron pipe decreases so rapidly that at the end of 10 years it is sometimes found to have lost as much as 50 per cent. of its original efficiency.

EXTENT TO WHICH THE FINDINGS OF MR. FREEMAN ARE RELIABLE.—Since Mr. Freeman's tables have been accepted without serious question it is but reasonable to assume that his find-

ings are in substantial accord with the observations of Fire Officers.

The velocity of flow, in actual fire service, is practically always between 15 and 30 ft. per second, and at velocities between these points there is little doubt of the correctness of Mr. Freeman's findings, for the writer has observed the difference between the pressure at the source of supply and the point of discharge, at fires during a period of many years, and found in every instance, that when computed, the results obtained were in substantial accord with those given by Mr. Freeman, and wherever a material difference was disclosed, ample reason was in clear evidence.

In view of the great value of the tables of tests it is most unfortunate that a statement, which appears to have little foundation in fact, should be circulated in connection with them.

The statement referred to, and which will be found at the foot of page 27 of pamphlets issued by the "National Board of Fire Underwriters," is: "Rough rubber lining is liable to increase the losses given in the table as much as 50 per cent."

It is not likely that it was Mr. Freeman's purpose to convey the idea that there was actually in use rubber lined hose in which the friction loss would be 50 per cent. greater than that shown in the tables.

That, however, is the interpretation which the statement has generally received. And since this may do much to impede the development of the subject it is deemed necessary to go fully into the circumstances that have given color of truth to this statement.

It must be understood, at the outset, that rubber

lining could be made so rough that it would increase the friction loss as much as 50 per cent.

The error is in holding that hose of such roughness may be found in the service of fire departments. It is extremely doubtful if any rubber hose lining was ever manufactured that would cause such an excessive increase in friction.

ANALYSIS OF THE ERROR IN RELATION TO THE RESISTANCE CAUSED BY ROUGH LINING.—This error applies with peculiar significance to the work of our calling and seems to be due to a misunderstanding of certain conditions with which every student of the subject is confronted, and of which students should be warned at the outset.

When it was thought that the character of the surface was one of the major factors in determining resistance, a decrease in the efficiency of ageing pipe, was attributed to the roughing of the surface due to rusting.

There are other reasons, than the roughing of the surface, for this loss of efficiency.

Rust and corrosion as well as sediment and other obstructions diminish the area of cross-section.

But even if the decrease in the efficiency of water pipe were solely due to the roughening of the surface of the pipe, it does not necessarily follow that rough hose lining would diminish the efficiency of hose to a like degree.

It is generally agreed both on account of its reasonableness, and because it is borne out by observation, that the smooth flow is broken at lower velocity of flow in rough than in smooth lined pipes.

This of necessity implies that the critical point is reached, and that turbulent flow commences, earlier. The result is that the plus resistance becomes a factor that has to be dealt with earlier in the case of rough, than of smooth, lined pipes. In other words the plus resistance is switched in at a lower rate of flow in the case of rough, than of smooth, lined pipes.

By the time the turbulent flow is in progress in the smooth pipe, the resistance that has been developed in the rough pipe may be considerably greater than that developed in the smooth. But as soon as turbulent flow is set up in the smooth pipe the line of resistance of both pipes should be practically parallel.

Thus the difference between the resistance in smooth and in rough lined pipes is numerically the same at low as at high velocities, while the proportionate resistance of the rough pipe is far greater at low than at high velocities.

If this be a correct interpretation of what takes place then if the friction loss in a rough lined pipe be 50 per cent. greater than that in a smooth at a flow of 3 ft. per second it will be little more than 5 per cent. at a flow of 30 ft. per second.

UNLINED HOSE.—The result of tests with unlined fabric hose has done much in support of the misconception of the effect of slight roughness on the resistance encountered by water flowing over or by a solid.

Any one who has had experience with unlined hose must have observed that its friction efficiency is much lower than that of rubber lined hose. For

this there is sufficient reason apart from the greater roughness of surface.

When water is forced through unlined hose much of it, at first, runs through the fabric. It is not until the hose ceases to leak that tests to determine friction or rate of flow can advantageously be made, and by that time the hose has contracted measurably. This may easily be established by clasping a wire tightly around the hose when the pressure is first applied and observing it after the fabric has ceased to leak.

The extent to which a slight contraction in the cross-section of hose will diminish its efficiency may be seen from the fact that if the diameter of a 3-inch line be diminished 1/16 of an inch the friction loss for any constant rate of flow will be increased 17 per cent.

SOURCE OF DATA ON WHICH IS BASED THE STATEMENT RELATIVE TO THE INEFFICIENCY OF HOSE HAVING ROUGH LINING.—There is no information available as to the source from which Mr. Freeman obtained the data upon which he based the statement that the friction loss would be 50 per cent. greater provided rough lined rubber hose were in use. For this reason it is impracticable to account absolutely for the error. How easily it might have developed may be seen not only from the facts already set forth, but also from facts that may easily be proved by experiment.

ILLUSTRATION.—At this test a 1½-inch nozzle was used on a stretch of six lengths of 3-inch hose. With a pressure of 170 lbs. maintained at the source

of supply, a pressure of 80 lbs. was recorded on the nozzle.

After the pressure at the source had been maintained at 170 for five minutes, and the pressure on the nozzle continued unvaryingly at 80 lbs., the nozzle was removed and replaced by another, of the same bore, but slightly more abrupt taper; with the new nozzle a pressure of 94 lbs. was recorded.

The nozzles were exchanged several times, but so long as the pressure at the source of supply continued at 170 the nozzles showed 80 or 94.

And a substantially corresponding difference in pressures was recorded when the pressure at the source was increased or diminished.

Calculations based on these findings give:

In the first case $\sqrt{80} \times 1.5^2 \times 29.7$ or approximately 600. Thus giving the loss of pressure due to friction at a flow of 600 gallons as $\frac{170-80}{3}$ or 30 lbs. per 100 feet.

In the second case $\sqrt{94} \times 1.5^2 \times 29.7$ or approximately 650 gallons indicate a friction loss of $\frac{170-94}{3}$ or 25 lbs. per 100 ft. for a flow of 650 gallons.

From this it is apparent that the utmost care is necessary in the selection of nozzles used at tests.

Where the relative efficiency of different kinds of hose is being questioned, the same nozzle should be used on the different lines and in all cases.

The efficiency of nozzles intended for use in ex-

perimental work should be carefully tested in the actual filling and emptying of tanks.

DIFFICULTY OF GETTING THE EXACT PRESSURE AT THE POINT OF DISCHARGE.—It is difficult to get the exact pressure at a nozzle, and calculations relative to friction, flow, etc., should not be based on the readings of any mechanical device, except such reading has in every case been verified by the use of a mercury column, or some other direct pressure device.

In view of all the difficulties to be encountered it is not to be wondered that Mr. Freeman was in error on one point.

This question has been inquired into at such length for the reason that if the statement were one of fact it would be a task without useful purpose to endeavor to apply the principles of the mechanics of fluids to the resistance which water encounters in flowing through hose lines. For sections of the lines being interchangeable coefficients of roughness could not be used and if the results arrived at were to be influenced by a factor that could not be allowed for, compiled results would not be as close to the facts as intelligent estimates.

VELOCITY.—Velocity means rate of motion.

ACCELERATION.—Acceleration is change in velocity, or change in the rate of motion.

When dealing with falling bodies, in the early part of this work, it was stated, in substance, that a freely falling body, starting from a state of rest passed over a distance of about 16 ft. in the first

second of its fall, and that the distance traversed in any space of time may be found by multiplying 16 by the square of the number of seconds that the body is falling.

The exact distance a body falls in the first second is 16.08 ft.

The velocity of a falling body at the end of the first second is 32.16 ft. The distance 32.16 ft. has been denominated the acceleration due to gravity, is the unit for measuring this form of acceleration, and its value is, in this work, represented by the letter g.

Since the velocity with which a body is moving at the end of any number of seconds, it has been falling, is equal to the product obtained by multiplying 32.16 by the number of seconds it follows that if velocity be represented by V, acceleration due to gravity by g, and time by t, the formula may be shown, in concise form, thus: $V = gt$.

Hence this is the formula for finding the velocity at which a body is moving at the end of any number of seconds, provided the body started from a state of rest, i.e., was let drop.

It has been found by experiment that half the sum of the initial and final velocities is the average velocity.

As in the case under consideration the initial velocity was zero, and the final velocity gt, the average velocity may be represented thus: $\frac{o + gt}{2}$

If h be made to represent the total height, or distance, through which a body moves in a given number of seconds, the formula for finding the total

distance a body moves within that time may be written $h = \frac{1}{2}gt \times t$ or its equivalent $h = \frac{1}{2}gt^2$.

SIMPLE PROBLEMS ON THE ACCELERATION DUE TO GRAVITY ARE: (1) The velocity acquired at the end of one second, by a freely falling body starting from rest. Stated to be 32.16 and represented in formulas by the letter g.

(2) The distance traversed in one second. Found to be 16.08 and represented as $\frac{1}{2}g$.

(3) The distance traversed in any number of seconds. Found by multiplying $\frac{1}{2}g$ by the square of the number of seconds.

If g be made to represent acceleration, h height, t time and V velocity

(1) May be written; (1) $V = gt$

(2) May be written; (2) $h = \frac{1}{2}g$ times t, if t equals one.

(3) May be written; (3) $h = \frac{1}{2}gt^2$

(a) If $t = 1$, formula (1) becomes $V = g$

(b) If $t = 1$, formula (3) becomes $h = \frac{1}{2}g$

(c) From formula (1) we derive the value $t = \frac{V}{g}$ as shown in the early part of the book. Substituting this value in formula (3) we have $h = \frac{1}{2}g \times \frac{V^2}{g^2}$ which is equal to $h\ \frac{1}{2}g \times \frac{V^2}{2g}$: Hence $V = \sqrt{2gh}$, showing that the velocity of a falling body varies as the square root of the distance it has fallen.

These formulas may be translated thus:

(1) The velocity of a freely falling body at the

end of any second of its descent is equal to 32.16 feet multiplied by the number of seconds.

(2) The distance traversed by a freely falling body during any second of its descent is equal to 16.08 multiplied by one less than twice the number of seconds.

(3) The distance traversed by a freely falling body during any number of seconds is equal to 16.08 feet multiplied by the square of the number of seconds.

BODIES HAVING INITIAL VELOCITY.—When a body is thrown downward the effect of the throw must be added to the effect of gravity.

BODIES THROWN UPWARD.—When a body is thrown vertically upward, gravity diminishes its velocity every second by 32.16 or g. The time of ascent may be found by dividing the initial velocity by the acceleration due to gravity:

$$t = \frac{V}{g}.$$

EXAMPLES.—Assuming for the present that g equals 32,

(1) What will the velocity of a body after it has fallen 5 seconds be?

SOLUTION.—$V = gt = 32 \times 5 = 160$. Answer: 160 feet per second.

(2) A body is projected vertically upwards at a velocity of 128 ft. per second. How high will it rise?

SOLUTION.—$t = \frac{V}{g} = \frac{128}{32} = 4$. Hence $t = 4$,

which supplies the value necessary in order that we may write the formula:

$$h = \tfrac{1}{2}gt^2 \text{ as, } h = 16 \times 4^2 = 256 \text{ ft.}$$

CARRYING DISTANCE OF STREAMS.—In problems relating to the carrying distance of streams, the velocity being known, the theoretical altitude it will reach, when discharged vertically may, in every case, be found by following the procedure shown in example (2).

VELOCITY OF DISCHARGE FOUND FROM NOZZLE PRESSURE.—It has been shown algebraically, and established by reasoning developed in connection with the demonstration, that the velocity of a freely falling body, at any point in its descent, is equal to the square root of 2gh.

The formula from which the velocity is derived is written: $V = \sqrt{2gh}$.

This formula is called Torrecelli's Theorem. If you fully understand this theorem and formula (2) immediately preceding you should find little difficulty in working out the theoretical altitude to which a stream will rise.

TO COMPUTE THE THEORETICAL ALTITUDE TO WHICH A STREAM WILL RISE.—Assuming a nozzle pressure of 100 lbs. It will be remembered that the velocity of flow is the same as that which a body would have acquired when it had fallen a distance equal to the distance from the surface of the water to orifice from which it is flowing.

A nozzle pressure of 100 lbs. will support a column of water 230 ft. in height. Therefore, the velocity of flow, under a nozzle pressure of 100 lbs.

is equal to the velocity which a freely falling body would have acquired when it had fallen a distance of 230 ft.

Fom this it may be seen that where the nozzle pressure is 100 lbs. the value of h, in the formula $V = \sqrt{2gh}$, is 230.

Since the value of g is constant and that of h ascertained the values may be substituted, and the formula written:

$$V = \sqrt{2 \times 32.16 \times 230}$$

$$\text{That is } V = \sqrt{14793.6} = 121.6$$

We have already seen that the velocity is always equal to gravity multiplied by the time. That is, $V = gt$, and we have seen that if

$$V = gt, \; t = \frac{V}{g}$$

We have also learned that $h = \frac{1}{2}gt^2$

Let $t = \frac{V}{g}$ be formula (1), and $h = \frac{1}{2}gt^2$ formula (2).

But the value of V is 121.6 in this case, and that of g always 32.16.

Hence by substituting, $t = \frac{V}{g}$ may be written

$$t = \frac{121.6^2}{32.16} = 3.78$$ by carrying over the values from formula (1).

Formula (2) becomes $h = \frac{1}{2}g \times \overline{3.78}^2$ or $h = 16.08 \times 14.3 = 229$ ft.

Thus 229 feet is the theoretical altitude to which a stream discharged at a pressure of 100 lbs. would ascend.

Whenever it is desired to find the altitude to which a stream will rise, the nozzle pressure being known or given. The value of h, in the formula $V = \sqrt{2gh}$ may be found by multiplying the pressure in pounds per square inch by 2.3, 2.3, being the height in feet of a column of water that will exert a pressure of one pound per square inch of surface.

HEIGHT TO WHICH A STREAM WILL RISE WHEN DISCHARGED FROM A NOZZLE UNDER A PRESSURE OF 200 *LBS. PER SQUARE INCH.*—With a nozzle pressure of 200 lbs. the value of h, in the formula: $V = \sqrt{2gh}$, is 460, and by substitution the formula may be written: $V = \sqrt{64.32 \times 460}$, which worked out becomes $V = \sqrt{29857}$ or 172, which represents the velocity in feet per second of a stream discharged at a pressure of 200 lbs. per square inch.

The velocity known it may be substituted in the formula: $t = \frac{V}{g}$ which may now be written

$$t = \frac{172}{32.16} = 5.35,$$ which represent the time in seconds that a stream discharged at a velocity of 172 ft. per second will continue to rise.

The value of t being known it may be substituted in the formula: $h = \frac{1}{2}gt^2$ which formula now becomes: 16.08×28.6 which equals 459.9, and repre-

sents the height in feet to which a stream discharged under a pressure of 200 lbs. will rise.

A nozzle pressure of 50 lbs. supports a head of 115 ft., thus making the value of h, in formula: $V = \sqrt{2gh}$, 115, hence with a nozzle pressure 50 lbs. that formula may be written $V = 16.08 \times 115$ which is 86, showing that the velocity of discharge under a pressure of 50 lbs. per square inch is 86 ft. per second. Then by substitution $t = \frac{V}{g}$ becomes $\frac{86}{32.16}$ or 2.67, thus the value of t is 2.67 and that of t^2 7.13, hence the formula: $t = \frac{1}{2}gt^2$ becomes $h = 16.08 \times 7.13$ or 114.7, the height to which a stream discharged at a pressure of 50 lbs. per square inch will rise.

RELATION BETWEEN VELOCITY HEAD AND THE HEIGHT TO WHICH A BODY PROPELLED VERTICALLY UPWARD WILL ASCEND.—We have seen that water is discharged from an orifice at a velocity equal to that which a freely falling body would have acquired when it had fallen a distance equal to the height above the orifice of the free upper surface of the water.

The acceleration due to gravity acts uniformly and with equal force whether a body is ascending or descending.

Therefore, a body discharged vertically upward will reach a height equal to that from which the body would have to fall in order to have acquired a velocity equal to that with which the ascending body is propelled.

Thus it is established that a body popelled vertically upward, with a velocity equal to that with

which water will flow from an orifice in the bottom of a tank, will reach a height equal to the level of the surface of the water.

COMPARISON OF RESULTS OBTAINED MATHEMATICALLY WITH THE REASONING OF THE MATTER.—To give a pressure of 200 lbs. per square inch requires a head of 460 ft. And we find by computation that water discharged under a pressure of 200 lbs. per square inch will reach a height of 459.89 ft.

A nozzle pressure of 100 lbs. requires a head of 230 ft. and the height to which a body, discharged at a velocity equal to that at which water at 100 lbs. will issue, would reach an altitude of 229.88.

A head of 115 ft. will give a pressure of 50 lbs. and a body propelled vertically upward at a velocity equal to that which a pressure of 50 lbs. would maintain will reach a height of 114.7.

So by reason and by mathematical computation we find that, except in so far as it is impeded by the resistance of the air, water will reach a height equal to the head supplying the pressure under which it is discharged. In other words water will find its level when discharged vertically upwards as well as when contained in pipes, tanks or reservoirs.

SCOPE OF THE RULE.—It seems that the rule just considered applies to all liquids of slight viscosity for the reason that the force necessary to impell any mass at a stated velocity is proportional to the specific weight of the substance of which the mass is composed, while the law of gravity operates without regard to the specific weight of an object.

OBSERVATIONS ON THE RULE.—From the problems dealing with the height to which streams discharged under stated pressures will ascend it may be observed that while 50 lbs. nozzle pressure gave a velocity of 86 ft. per second it required 200 lbs. to produce a velocity of twice 86 or 172 lbs.

Hence, to double the velocity it is necessary to apply four times the energy, but if the velocity be doubled the altitude attained by a body projected vertically upward is increased four times.

This suggests that an increase in the velocity of a given body increases the energy of that body twice as rapidly as the increase in velocity. That is, the mass being the same the energy increases as the square of the velocity.

This suggestion is further borne out by the fact that the striking energy of a falling body is proportionate to the height from which it has fallen while the ratio of the velocity it attains is only one-half as great. Or in other words, if a body falling from a height of 8 ft. has a striking energy of 10 lbs. it will, on being dropped from a height of 34 ft. have a striking energy of 40 lbs. although the striking velocity in the first case is 22.55 ft. per second while in the second case it is only 45.25 ft. per second.

RANGE OF STREAMS

RANGE OF STREAMS.—Difficult as is the subject of hydraulics, and wide as is the range that frequently appears between theory findings and performance, there is no branch of the subject wherein theory and practice differ more widely than in the range of streams. Yet, as it is only through an un-

derstanding of the underlying principles involved, that ability may be acquired to conduct investigations that may lead to a fuller comprehension of what results may reasonably be expected from the application of specified forces, hence it is deemed best to present the theory of the subject. When a body is projected upwards, at any angle other than one of 90 degrees with the horizontal, the proportion of the whole energy of projection that is expended in carrying the body away from the earth varies as the angle which a prolongation of the path, which the body assumed at the outset, makes with the surface of the earth.

If the body at first assumes an angle of 30 degrees, one third of the whole energy, expended in propelling the body, acts in carrying it away from the earth, while two-thirds carry it horizontally.

If the angle be one of 45 degrees one-half the propulsion energy is expended in carrying the body away from the earth while the other half carries it in a horizontal direction.

To double the velocity of discharge it is necessary to increase the propelling force four times. Hence when the energy of propulsion is doubled the velocity of discharge is increased one-half, or fifty per cent., and when the propelling power is reduced one-half the velocity of discharge is reduced one-fourth.

Where the angle and the total velocity of discharge are known the height to which a body will rise may be found by computing the height to which a body would rise if propelled vertically at a velocity equal to that at which the body considered draws away from the earth.

Initial velocity is due solely to energy of propul-

sion, and is wholly uninfluenced by direction; it, therefore, follows that the horizontal velocity is equal to the whole velocity less the vertical velocity.

Horizontal velocity is wholly unaffected by the fact that the total velocity of a projectile (body propelled) diminishes as the projectile ascends, the entire diminution being loss in vertical velocity.

In like manner the horizontal velocity of a projectile is not increased by the fact that the total velocity becomes greater as the body descends.

As the horizontal velocity of a projectile is constant throughout its entire journey, it follows that the course of a projectile is a parabola, and the second half of its path is an exact reproduction of the first. If the path of a projectile could be marked off on a plane, and bent back at the point where it reaches its greatest altitude the two divisions would coincide throughout their entire length.

As there is one instant during the flight of a projectile when its path is in a true horizontal line, and as this instant is the one at which the projectile has attained its greatest altitude, it follows that what is necessary in order to determine the range is to multiply the horizontal velocity by the time required for a body to fall from a height equal to the greatest attained by the projectile during the flight considered. The result multiplied by two will give the theoretical range.

COMPUTING THE RANGE OF STREAMS.—The theoretical range of any body projected is greatest, when it is discharged at an angle of 45 degrees. As the angle of discharge varies from 45 degrees the range varies as the variation of the angle.

A stream is discharged at an angle of 45 degrees, under a nozzle pressure of 100 lbs. The range (theoretical) will be:

Pressure being 100 lbs. the value of h, in the formula $V = \sqrt{2gh}$, is 230 and the value of V, 121.6.

But the horizontal velocity is only $121.6 - \frac{121.6}{4}$ or 91.2.

We have already seen that the value of V is the same as gt; thus the formula $V = gt$ may be written $t = \frac{V}{g}$. But V has a value of 91.2 and g a constant value of 32.16. Hence this formula may be written $t = \frac{91.2}{32.16} = 2.836$. That is, a stream discharged at a nozzle pressure of 100 lbs. will continue to ascend for a period of 2.836 seconds and moving during that period with a horizontal velocity of 91.2 ft. per second, it will have at the point of maximum altitude a horizontal travel distance of 91.2×2.836 or 258.6 ft.

If the nozzle pressure were 200 lbs. per square inch the value of h, in the formula $V = \sqrt{2gh}$, would be 460 and the value of V 172, while the horizontal velocity would be $172 - \frac{172}{4}$ or 129 ft. per second. But the vertical velocity would also be 129 ft. per second which would cause the stream to continue to

rise for a period of $t = \frac{V}{g} = \frac{129}{32} = 4$ seconds and the distance in a horizontal line from nozzle to the point where the stream reaches its greatest altitude is 129×4 or 516 ft.

With a nozzle pressure of 50 lbs. the value of h in $\sqrt{2gh}$ is 50×2.3 or 115, the value of V is found to be 86, and the vertical and horizontal velocities are each $86 - \frac{86}{4}$ or 64.5.

$$\text{But } t = \frac{V}{g} = \frac{64.5}{32.16} = 2.005$$

$$\text{And } 64.5 \times 2.005 = 129.3 \text{ ft.}$$

A comparison of the results obtained where streams are directed vertically upwards, and where they are discharged at an angle of 45 degrees, shows that a stream directed at the latter angle reaches a height one half as great as if a stream at equal pressure was directed vertically upwards.

STREAMS DISCHARGED AT AN ANGLE OF 30 *DEGREES.*—In discussing the range of streams, when discharged at an angle of 45 degrees, it was pointed out that when the energy of propulsion was diminished one half, the velocity of discharge fell off one-fourth. That is, the velocity of discharge fell off only one half as fast as did the energy of propulsion.

When a mass of matter of any nature, including a stream of water, is discharged at an angle of 30 degrees the energy carrying the matter away from the earth is only one-third of the total energy.

In order to ascertain the magnitude of the energy expended in carrying the matter away from the earth it will be necessary to subtract from the total energy two-thirds of its own value, but since the energy is represented in velocity, we subtract one-half of two-thirds or one-third of the actual velocity. Under these circumstances two-thirds of the total energy of propulsion is expended in propelling the body horizontally, hence the remaining one-third must be subtracted from the total energy, which may be done by subtracting from the actual velocity, one-half of one-third or one-sixth its value.

A stream is discharged at an angle of 30 degrees, and at a nozzle pressure of 50 lbs.

It has been shown that a nozzle pressure of 50 lbs. insures a velocity of discharge of 86 ft. per second. Hence the velocity with which it shall recede from the earth when discharged at an angle of 30 degrees is $86 - \frac{86}{3}$ or 57.3, while the horizontal velocity is $86 - \frac{86}{6}$ or 71.7.

Since the vertical velocity is 57.3 the stream will continue to rise for a period of, $t = \frac{57.3}{32.16}$ or 1.785 sec. Hence the distance such a stream will travel before reaching its maximum altitude is 71.7×1.785 or 128 ft., which is one foot less than when a stream at 50 lbs. was discharged at an angle of 45 degrees. Angle 30 degrees and pressure 200 lbs. Here the actual velocity is 172 ft. per second. While

the vertical velocity is $172 - \frac{172}{3}$ and the horizontal velocity $172 - \frac{172}{6}$ and the value of t in the formula $t = \frac{114.7}{32.16}$ or 3.567 the horizontal distance to the highest point of stream 143.3×3.567 or 511 ft. which is 5 ft. less than when a stream at 200 lbs. was discharged at an angle of 45 degrees.

APPARENT ANGLE OF DISCHARGE DECEPTIVE.—The direction of a stream's discharge makes a much broader angle with the horizon than it appears to make.

The instant that a stream is projected beyond a nozzle the pull of gravity, by drawing the stream out of its projected course, makes the angle of discharge appear much narrower than in reality it is.

The extent to which the apparent angle with the horizontal is narrowed, in this way, may be seen from the fact that a stream discharged at an angle of 45 degrees, and at a pressure of 100 lbs. would, if it continued in its original course, form the hypotenuse of an isosceles right triangle, one of the sides of which would be, as has been pointed out in a preceding problem, 258 ft. That is, if the stream pursued its original course, until it traversed a horizontal distance equal to that which a stream discharged at the same pressure and angle does traverse, it would reach a height of 258 ft., while as a matter of fact the altitude actually reached by such

a stream is only 129 ft., or 50 per cent. of what it would be if it pursued its original course. So that when a stream is discharged at an angle of 45 degrees it pursues a path such that if a straight line were drawn from its highest point of travel to the point of propulsion, this line would make an angle of 22½ degrees from the horizontal.

The more acute the angle which the path of direction makes with the horizontal, the more pronounced the flattening effect of the gravity pull, for the less the angle, the less the percentage upon which the constant force of gravity is exercized.

METHOD OF COMPUTING RANGE OF PROJECTILES.—In order to compute the range of projectiles, it is necessary to know the velocity of discharge and the angle of direction. From these data the maximum height to which a projectile will ascend is determined. The length of time it would take a body, starting from a state of rest, to fall a distance equal to the maximum height attained, multiplied by the horizontal velocity of discharge, gives the horizontal distance of the second half portion of the projectile's flight, which being a counterpart of the first portion is one-half the theoretical range.

REASONS FOR VARYING FROM THE METHODS EMPLOYED IN COMPUTING THE RANGE OF PROJECTILES.—The distance over which the liquid moves during that portion of the flight of a stream in which the liquid is drawing away from the earth has here been computed, in lieu of the distance it traverses in the second half because it was feared it would confuse the subject to follow the method employed by military mathemati-

cians, and then explain that this did not apply to the second, but only to the first, half of a stream's flight.

ALLOWANCES MADE ON ACCOUNT OF AIR RESISTANCE.—From the theoretical results obtained, deductions are made on account of the friction due to the resistance of the air.

These allowances vary according to the velocity of propulsion and the angle of direction, also for the direction and force of the wind and some minor considerations. The data, used in determining the proper allowances (as they are called) to make, have been obtained from tests. The allowances made for frictional and other resistances when treating of solid bodies do not seem to be properly applicable to projected liquid streams.

EXTENT TO WHICH THE SAME PRINCIPLES APPLY TO PROJECTED SOLIDS AND LIQUIDS.—While a stream is ascending, the water constituting it is in the form of a compact mass and hence appears to be sufficiently like a solid to justify the application of similar methods in computing its carrying distance. While a stream is ascending, the particles that constitute the mass of water are subjected to negative acceleration, hence the particles in advance are moving less rapidly than these succeeding. This causes an increase in the cross-sectional area of the stream. The stream does not break if discharged from a properly shaped nozzle, but continues as a stream until the point of maximum altitude is passed.

LIMITS OF THE DISTANCE TO WHICH THE

RANGE OF A PROJECTED LIQUID STREAM MAY BE COMPUTED AS ARE THE RANGE OF SOLIDS.—In order to bring out the reasoning on this phase of the subject it is necessary to treat it broadly.

Where a stream is discharged vertically downward the particles of water constituting the stream hold together, although, owing to the positive acceleration to which the stream is subjected, the particles in advance are moving at a higher velocity than those succeeding them. The stream loses cross-section (grows thinner) as it descends. There are three circumstances, each of which contributes in part to causing the stream to thin out rather than break, as it might be expected to do owing to the fact that the particles in advance must of necessity exercise some pulling effect on those succeeding.

The circumstances that cause the descending stream to thin out rather than break are:

(1) The cohesion of the particles cause them to cling together.

(2) The viscosity of the liquid enables it to resist the shear. This viscosity must be overcome before the stream becomes broken.

(3) The resistance which the air offers to particles which tend to become detached from the mass of advancing liquid, and the fact that at some period in the separation of the particles there must be some degree of partial vacuum, for air cannot occupy the space between the particles until some degree of separation has been affected.

WHERE THE MAJOR PORTION OF A STREAM'S MOTION IS HORIZONTAL.—When

a stream moving horizontally passes the point of maximum ascent, the acceleration due to gravity acting affirmatively causes the particles in advance to move more rapidly than those following.

Unlike the case of where the stream descends vertically, the acceleration is not in line with the direction of the major movement of the stream's motion, but at right angles to it. Hence the stream cannot, by thinning out, retain its continuity.

The forces that causes the particles of water in a stream descending obliquely to adhere, counteracts the effect of the acceleration, for a time, the extent of which, like the friction due to air resistance, awaits empirical determination.

As the stream does not thin out as its velocity increases, it is perforce bound to break, so at some point in the descending portion of the flight the pull of gravity overcomes the forces that, up to that point, held the particles together. When this occurs the stream breaks.

At breaking, the mass of water does not, as might be expected, assume the form of drops but breaks into bodies of liquid of irregular shapes and volumes.

EFFECT OF THE STREAM'S BREAKING UPON THE RANGE.—When a stream breaks, the amount of surface that becomes exposed to the resistance of the air is much greater than that which was exposed while the stream was intact. Thus the resistance encountered is vastly in excess of that which a stream in a compact form would encounter. And as a result the descending portion of the flight of a body of water, projected in the form

of a stream, is not nearly as great as is the ascending portion of the flight.

FORCES HOLDING PARTICLES OF WATER TOGETHER AFTER STREAM HAS PASSED THE POINT OF MAXIMUM ALTITUDE.—Once a stream passes the point of maximum ascent the forces that hold the particles of water together must be, owing to the greater velocity of motion of the particles in advance, almost infinitely small as the pull due to acceleration becomes more than the cohesion and viscosity are able to counteract almost immediately as the stream commences its descent. How slight are the forces holding the particles of water together under such circumstances may be noted by observing the culmination of a stream discharged, at a considerable angle of elevation and at a goodly pressure, in a moderate breeze.

Where a stream is discharged in the face of a wind, the stream ascends at an angle closer to the vertical than when the angle of nozzle direction is the same and the stream discharged in a calm. The stream rises higher, and at a maximum of ascent is blown away in the form of a fine spray, showing that, the instant the particles in advance commence to outspeed those succeeding, the stream loses its power of resistance. Where a stream is discharged at right angles to a breeze the distance it moves before breaking is not materially different from that at which it passes its point of maximum altitude if discharged at equal angle and like pressure in a calm. This indicates that while a stream is ascending it retains its power to resist disintegration by the wind.

RELATION BETWEEN THE RANGE OF PROJECTILES AND THE DISTANCE TRAVERSED WHEN PROPELLED VERTICALLY. —Many persons seem puzzled by the statement that, the velocities of propulsion being equal, the horizontal range of a projectile is greater than twice the altitude it will reach. The confusion seems to arise from overlooking the fact that horizontal velocity is not diminished by gravity. An attempt is here made to clear the confusion upon that point. A projectile directed vertically at a given velocity will continue in transit for a longer period than if projected at equal velocity at any other angle. But when the direction is vertical the whole of the velocity is subjected to the pull of gravity while when the propulsion is in an oblique direction the horizontal velocity is unaffected, and the greater average velocity that results from the horizontal velocity being unaccelerated more than counteracts the loss due to the shorter period of transit. As the maximum range is attained when the angle of propulsion is one of 45 degrees, this matter may be best illustrated by a comparison of the relative distances traversed by a body propelled vertically and one propelled at an equal velocity at an initial angle of 45 degrees.

A stream discharged at a nozzle pressure of 50 lbs. per square inch has an initial velocity of 86 ft. per second, and will consume 2.67 seconds in its ascent. With an initial velocity of 86 and a final velocity of zero, the average velocity is $\frac{1}{2} \times 86$ or 43, and 43×2.67 equals 115. In falling back to the point of propulsion the water would traverse an equal distance making in all 230 ft. In other

words, the total distance that water directed vertically will traverse before it reaches the level from which it was própelled is equal to the product of ½ the initial velocity by the time consumed in the ascent.

When a stream is discharged at an angle of 45 degrees the horizontal velocity is ¾ of 86 or 64½ ft. per second, the vertical velocity is also 64½ ft. per second, and such a stream will continue to rise for a period of 64½ ÷ 32.16 or 2 seconds, hence the horizontal distance traversed is equal to twice 64½ × 2 or 258 ft. In other words the horizontal range of a stream discharged at an angle of 45 degrees is equal to the product of ¾ of the initial velocity in feet per second by ¾ the time the water would be in transit if the stream were directed vertically.

In the case of the stream discharged vertically the distance traversed is equal to the product of ½ the initial velocity by the time water is in transit, while when discharged at an angle of 45 degrees the distance traversed is equal to the product of ¾ the initial velocity by ¾ of the time the water would be in transit if the stream were directed vertically.

EFFECT OF NOZZLE DESIGN ON THE RANGE OF STREAMS.—The angle of direction and the pressure of discharge determined, the type of nozzle used constitutes the most important single factor in limiting the range of streams.

A study of water, in motion, discloses an extreme sensitiveness on its part to any obstructions or irregularities in its path. In no other respect is the result of such obstructions so pronounced as in diminishing the range of streams. Nor is there any

other point in the course of flow at which an obstruction so impedes the velocity as at the point of discharge. The reason for this is that whatever the direction in which particles were moving before reaching the point of discharge they are at that point compelled to assume a direction in accordance with that being pursued by the main body of the stream.

Every student of fire craft is familiar with the so-called choking effect to which water is supposed to be subjected when discharged from nozzles at high pressure. Choking (so-called) is entirely due to improper nozzle design.

There is no good cause, apparent either to science or to reason, why water discharged at a nozzle pressure of 100 lbs. per square inch should not flow as smoothly as water discharged at a pressure of 10 lbs.

The choking effect is much more marked at high pressures, because first, the greater the pressure the more gradual must be the taper in order to give a smooth flow, and second, the higher the pressure the greater the velocity of flow and the greater the amount of energy expended in altering the direction in which the particles of water (that approach the nozzle opening obliquely) are moving.

Where an abruptly tapered nozzle is employed some of the particles of water approach the discharge opening from a direction that tend to carry them across the path of the main stream. All the particles on the outer circumference of a stream, from such a nozzle, have this tendency of direction. And a considerable amount of the total energy of discharge is dissipated by a confliction of the energy

which those particles convey, with the energy conveyed by the particles towards the center of the stream. The roaring sound that accompanies the so-called choking is caused by the commotion among the deflected particles.

Where a nozzle has a very abrupt taper, the water does not issue in a true stream formation but in a jumbled mass of molecules which soon lose their compact formation and being acted upon, while in a spray-like form, by the force of the wind or the resistance of the air, are either blown away or fall to the ground.

ACTUAL RANGE OF STREAMS.—In the absence of skilfully conducted and carefully observed tests, little that is authoritative, can be said on the actual range of streams.

Observations made in connection with actual fire service are of little or no value, as an aid in this phase of inquiry, on account of the extent to which range is limited by the shape of nozzles.

Reference will be had only to such tests as gave the best results observed.

The best results noted were obtained by the use of a nozzle 12 inches long, which tapered from 3 inches to 1¾ inches. This nozzle lost 1 inch of diameter in the 7 inches toward the hose and ¼ inch in the 5 inches toward the discharge opening.

VERTICAL CARRYING DISTANCE.—Where the nozzle just described was used, a stream discharged at a pressure of 30 lbs. per square inch reached a height of 66 ft. At 50 lbs. a height of 108 ft. was reached.

At pressures in excess of 50 lbs. accurate measure-

ments were not taken, but at 70 lbs. the estimated height was 140 ft., while at 100 lbs. estimates were that the stream reached a height of 190 ft.

In tests to determine the maximum altitude which streams will reach, care should be taken to so direct nozzles that the water in falling does not impede the ascending column, while the deflection of the stream from the vertical should be as slight as is consistent with the accomplishment of this purpose.

From the foregoing it will be seen that with the nozzle in question a stream discharged at a nozzle pressure of 30 lbs. reached a height almost equal to 96 per cent of the theoretical, at 50 lbs. a height equal to 93 per cent, at 70 lbs. a height equal to 88 per cent (estimated), at 100 lbs. 83 per cent (estimated).

HORIZONTAL CARRYING DISTANCE.—Due to causes before stated stream formation ceases soon after water passes the point of maximum ascent, the stream may, however, continue its flight for a considerable distance beyond a perpendicular to that point. It is the total distance that water traverses in its flight that is considered under this heading.

The same nozzle as that used to determine the maximum altitude was employed in the tests, the results of which are here outlined.

In the tests that are now to be discussed the angle of discharge was 30 degrees from the horizontal in each case. The 30 degree angle was selected, because that seems to be the angle at which the actual carrying distance is greatest. At 45 degrees, the angle of maximum theoretical range, the water became so thoroughly broken up that it was difficult

to determine, within a considerable area, where the greater portion of the water fell.

With a pressure of 30 lbs. the water fell at a distance of 130 ft. from the nozzle; with 50 lbs. at a distance of 210 ft.; with 70 lbs. at a distance of 280 ft., and with 100 lbs. it carried a distance of 360 ft.

By comparing the results obtained, at equal pressures, in the two series of tests, it may be observed that the horizontal carrying distance is in each case substantially twice the elevation attained. In this connection it is pertinent to note that water thrown vertically traverses twice the computed distance before its energy of motion is expended. That is, in falling back to the point of starting, it traverses a distance equal to that traversed in ascending.

Should a skilfully conducted series of tests show the horizontal carrying distance is twice the altitude a stream will reach, it would much simplify computing, as the exact elevation may easily be determined, and as the theoretical elevation is equal to the head which the nozzle pressure would support.

With these data as a guide no great difficulty should be encountered in determining the type of nozzle that will give the maximum reaching power as well as disclose other information helpful to the development of the science of the calling.

EFFECTIVE RANGE OF STREAMS.—So many different considerations would have to be taken into acount in order to discuss this question fully that it is impracticable to treat every phase of it. It will, therefore, be necessary to outline briefly the viewpoint from which it is to be considered.

Effective distance, as here considered, is the greatest distance from which a stream may be used, to sufficient advantage, to justify the expenditure of the amount of energy requisite to its operation where there is no other point of vantage on the same side of a fire from which a stream can be advantageously operated. But even though the subject be thus limited it will still require somewhat elaborate discussion in order to properly develop the ideas involved.

In discussing the effective range the type of nozzle is just as significant as in dealing with the actual range. And as some types of nozzles have fully 50 per cent less discharge distance than others, the effective range of streams commonly found in use will be considerably less than what is here stated. It should be understood that what is here stated as the effective range is the effective range only where the best type of nozzle is used.

The distance from a nozzle at which a stream may be regarded as sufficiently effective to justify its use depends to a great extent upon the purpose it is sought to accomplish. Where a fire is sweeping between the beams of an open beam ceiling a stream is not effective unless it can hit up between the beams. In order to do this it will be necessary to take the pipe within 15 or 20 ft. of fire. Under such circumstances 15 or 20 ft. may be regarded as the effective range, whatever pressure may be on the line. This is merely an example of the extent to which the effective range may be limited by a variety of impedence that have nothing, directly, to do with pressure or with nozzle efficiency.

It is frequently desirable to hit ceilings with

streams directed from positions outside of buildings. And the distance to which this may be done is often treated, in discussions on the subject, as the effective range of streams.

It was adherence to this viewpoint, in connection with the performance of the average nozzle, that resulted in the adoption of the old rule of one foot for each pound of nozzle pressure.

Although the rule just considered is an approximately accurate statement of the effective range of streams, taking as the bases of the estimate the average result obtained from the different nozzles found in use, yet it is not exaggeration to say that the best type nozzle is capable of delivering an effective stream a distance of from 30 to 50 per cent in excess of this. The higher the pressure the greater the disparity between nozzles of high and those of doubtful efficiency.

EFFECTIVE RANGE DEPENDS ON WHAT IT IS PROPOSED TO ACCOMPLISH BY USE OF A STREAM.—For some forms of fire service the effective carrying distance of streams is substantially equivalent to the actual carrying distance.

Instances of service under which the actual and the effective carrying distance of streams are equal are:

(1) Where streams are used to form water curtains or spray shields between flaming and endangered property, and to prevent fire communicating from floor to floor of a building by way of exterior exposures.

(2) To wet down shields under cover of which men may advance closer to extremely hot fires than

would be possible without portable protection, and to keep men and their clothing wet while occupying positions where they are exposed to great heat.

(3) To flood floors above fires.

(4) To cool down exterior stairs, fire escapes, ladders communicating between balconies, iron shutters, etc., etc.

(5) To wet down combustible material exposed to intense heat or great radiant energy.

KINETIC ENERGY OF MOTION CONVERTED INTO POTENTIAL ENERGY.—Potential energy can generally be converted into kinetic and kinetic energy into potential without great waste. But when a great amount of energy has been expended in propelling a small volume of water, at high velocity, within a rigid container, it requires nice proportionality of parts to insure, without great waste, a conversion of the energy so contained into work, as it is necessary to do in order that streams may carry great distances, or to convert it (the kinetic) into potential energy in the form of increased pressure as is done in connection with centrifugal pumps.

The development of methods by which the potential energy contained in water flowing at high velocities may be made available for further work has been the subject of much investigation, calculation, experiment and observation by scientists, mathematicians, and mechanical engineers, particularly in connection with the development of the centrifugal pump. Pumps of this type have been developed, by means of which it has been found practicable to move water economically by the operation of an impeller

in such manner as to cause the propulsion of water to very high velocities in areas of low pressure, and converting the energy developed in this manner into pressure by conducting the water away from the pump through graduated passages.

But, while it has been found possible to do this, it has also been found that a very slight change in the graduation or taper, of the passages may result in a total waste of the kinetic energy due to velocity, leaving nothing available from the operation, except the potential energy which the water received in the form of push from the impeller.

The flow of water from nozzles has never been the subject of careful scientific observation, but it appears reasonable that the improper graduation of nozzles is as wasteful of energy as is the improper graduation of centrifugal pump passages. What is sought in each case is to convert the energy of high velocity flow into work, or into a form available for work.

If, upon investigation, it should develop that improperly shaped nozzles are as destructive of energy as improperly shaped pump passages (i.e. that they destroy the whole of the energy due to motion), then the carrying distance of a stream from such a nozzle will be only one-half that of the theoretically perfect nozzle, where such nozzle is used on hose having a diameter twice that of the nozzle.

DIFFICULTY IN DETERMINING THE TYPE OF NOZZLE BEST ADAPTED FOR FIRE SERVICE.—The difficulties in determining the type of nozzle best suited for fire service are:

(1) The shorter a nozzle the less the loss due to

friction in it and the higher the pressure that can be maintained on it. That is, the short nozzle has apparent strength to cloud its actual weakness.

(2) The shorter a nozzle the less likely it is to be efficient on account of its necessarily abrupt taper.

(3) The longer a nozzle, provided it is properly tapered, the more efficient it is, but the more difficult it is to maintain pressure upon it. Thus its real merit is clouded by an apparent weakness.

(4) A taper sufficiently gradual for ordinary velocities of flow is too abrupt for the high velocities that result from high nozzle pressures. Hence a nozzle that may be sastisfactory for one kind of service may not be suitable for another.

(5) The more efficient a nozzle is the more difficult it is to maintain pressure on it, hence the interest of manufacturers of pumping apparatus is to confuse the subject of nozzle efficiency.

By way of suggestion it may be said that where nozzles of inferior efficiency are used under high pressures the water makes a hissing sound in coming from them. The stream appears whitish and spreads soon after leaving the nozzle.

RELATION BETWEEN SIZE OF NOZZLES AND RANGE OF STREAM.—Men assigned to water towers and others having exceptional opportunities for observing streams discharged from outside positions place great faith in the carrying powers of streams from large-sized nozzles.

For the superiority of the larger nozzles there are four reasons:

(1) The larger the discharge end the more gradual the taper.

(2) The larger the discharge end the greater the volume of water that approaches the opening in a direct line and the less the smooth flow is disturbed by the particles that approach the opening obliquely.

(3) The larger the stream the smaller the relative area of surface exposed to the resistance of the air. This is regarded as a very important factor in determining the range of military projectiles.

(4) At a given pressure the actual velocity is slightly greater in large than in small nozzles.

The first two of these causes could be obviated by a proper design of small nozzle, while if small nozzles were properly graduated the effect of the causes stated under the headings of three and four would be practically negligible.

That the diameter of a nozzle is not a controlling factor in determining the range of streams may be seen from the fact that a one-eighth-inch petcock will deliver a stream farther than some large nozzles found in use, provided it be subjected to the same pressure as the nozzle.

PRACTICE EXERCISES
PART II.

(1) What is weight?

(2) What is density?

(3) What is specific gravity?

(4) What is temperature?

(5) At what temperature does water reach its maximum density?

(6) What is the standard weight of a cubic foot of water?

(7) What is the volume in cubic inches of one gallon of water?

(8) What is the weight of the water that one length of 3 in. hose will contain?

(9) What is the weight of the water that will fill a standpipe 6 in. in diameter and 460 ft. in height?

(10) What is the total internal stress on the inner surface of one length of 3 in. hose if the pressure be 100 lbs. per square inch?

(12) A block of granite having a volume of one cubic foot weighs 170 lbs. in air: (a) What would it weigh in water? (b) What is the specific gravity of the kind of granite in the block?

(13) A ¼ in. pipe 115 ft. high is filled with water: (a) What is the pressure per square inch at the lower end of pipe? (b) What is the total weight of the water in the pipe? (c) What is the total weight supported by the bottom of the pipe?

(14) What is the cross-sectional area in square inches of a 2½ in. line, of a 3 in. line, of a 3½ in. line?

(15) What length of $2\frac{1}{2}$ in., 3 in., and $3\frac{1}{2}$ in. lines will respectively contain one gallon of water?

(16) What is meant by rate of flow in gallons per minute? What by velocity in feet per second?

(17) With a flow of 400 gallons per minute: (a) What is the velocity of flow in feet per second, in $2\frac{1}{2}$, 3, and $3\frac{1}{2}$ inch hose? (b) What through $1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{3}{4}$ in. nozzles.

Ans.—26, 18, and 13, for hose.

Ans.—108.7, 72, and 54, for nozzles.

(18) What relation exists between the rate and the velocity of flow?

(19) What causes friction?

(20) What effect has pressure on the friction encountered: (a) Where one solid is moved over the surface of another? (b) Where water flows over the surface of a solid?

(21) In what terms are amounts of friction stated?

(22) Give the three most important factors in determining the amount of friction under conditions of water flow such as are commonly encountered in fire service.

(24) What is the loss of pressure due to friction in 100 ft. of 3 in. hose when the velocity of flow is 20 ft. per second? Formula. $F = \frac{V}{D} + \left(\frac{\frac{1}{2}V}{D}.\right)^2$

$$F = \frac{20}{3} + \left(\frac{20}{2x3}\right)^2 = 6.66 + 11, = 17.6 \text{ lbs. per sq. in.}$$

(25) What is the friction loss in 100 ft. of $2\frac{1}{2}$ in. hose when the velocity of flow is 40 ft. per second? Ans. 80 lbs. per sq. in.

(26) What is the friction loss in 100 ft. 3½ in. hose when the velocity of flow is 30 ft. per second? Ans. 27.1 lbs. per sq. in.

In (24) there is a flow of 444 gal. per min. In (25) a flow of 600 and in (26) a flow of 900 gal. per min.

(27) What is the friction loss in pounds per square inch for each 100 ft. of: (a) 2½ in. hose with a flow of 400 gal. per min? (b) 3 in. hose with a flow of 600 gal. per min. (c) 3½ in. hose with a flow of 800 gal?

As stated elsewhere, the formula: $F = \frac{V}{D} + \left(\frac{\frac{1}{2}V}{D}\right)^2$ is intended to be used only at rates of flow between 15 and 35 ft. per second, and great accuracy is not claimed for it.

Where the rate of flow is less than 15 or more than 40 ft. per second or where exact conformity with the results obtained from tests is essential the formula should be written $F = \frac{V}{D} + \left[.54\left(\frac{V}{D} - \frac{D}{R^4}\right)\right]^2$

This formula is intended to be used only where computations refer to pipes of from two to four inches in diameter.

(28) What is the loss of pressure due to friction in 100 ft. of hose with a velocity flow of 6 ft. per second: (a) In 2½ inch hose? (b) In 3 inch hose? (c) In 3½ inch hose?

(29) What is the loss of pressure due to friction with a velocity flow of 50 ft. per second in 2½ inch, 3 inch, 3½ inch hose?

(30) What is the loss of pressure due to friction

per 100 ft. of 2½ in. hose with 70 gallons per minute flowing? With 140 gallons flowing in 3 inch hose? With 140 gallons flowing in 3½ inch hose?

(31) What is the loss of pressure due to friction in 100 ft. of 3 inch hose with a flow of 1,100 gallons per minute?

$$F=\frac{V}{D}+\left[.54\left(\frac{V}{D}-\frac{D}{R^4}\right)\right]^2$$

$$F=\frac{49.7}{3.}+\left[.54\left(\frac{49.7}{3.}-\frac{3}{5}\right)\right]^2$$

$$F=16.6+[.54(16.6-.6)]^2.$$

$$F=16.6+74.8=91.4\text{ lb.}$$

(32) With a 2 inch nozzle operated at a pressure of 80 lbs. per sq. in. what is: (a) The discharge in gallons per minute? (b) The rate of flow in the tube of the water tower on which the nozzle is being operated? (c) The velocity with which the water leaves the nozzle? (d) If the tube of the water tower is 5 inches internal diameter what is the velocity flow in the tube? (e) The friction loss per 100 ft. in the tower tube? (f) The total friction loss, if the tower tube and the section of line connecting it with the reservoir have a combined length of 80 ft.

(33) What is the friction loss per 100 ft. of 6 inch standpipe with 2500 gallons per minute flowing? In computing this allow the same relative efficiency to standpipe as has been allowed for hose.

(34) If the friction loss in 500 feet of 2½ inch hose with a flow of 70 gallons per minute is 7 lbs. per square inch, what is the friction loss in 300 ft. with a flow of 700 gallons per minute?

(35) If the friction loss in 500 ft. of 3 inch hose with a flow of 160 gallons per minute is 12 lbs. per square inch, what is the friction loss in 200 ft. with a flow of 1,100 gallons per minute?

(36) If the friction loss in 400 ft. of 3½ inch hose with a flow of 240 gallons per minute is 10 lbs. per square inch, what is the friction loss in 1,000 ft. at a 1,000 gallons per minute flow?

(37) If the friction loss in 100 ft. of 2½ inch hose with a flow of 400 gallons is 36.2 lbs., what is the friction loss in (a) a 3 inch line with equal flow? (b) a 3½ inch line with similar flow?

(38) What relation does acceleration bear to velocity?

(39) What causes water to leave a nozzle at such high speed?

(40) If water flows at a velocity of 30 ft. per second in a 3 inch line and is discharged through a 1½ inch nozzle, at what velocity does the water leave the nozzle?

(41) If the nozzle used in the question immediately preceding this is one foot long the whole difference between the velocity with which the water moves in the hose and the velocity with which it leaves the nozzle is gained in one foot. What is the rate of acceleration from the base to the discharge end of the nozzle?

(42) A body starts from a state of rest and falls freely: (a) What is its velocity in feet per second at the end of the first second of its fall? (b) How far did it move in the first second? (c) What is its velocity at the end of two seconds, and how far did it move in the first two seconds? (d) What

was the average velocity for the first second, for the first two seconds?

(43) A body is projected upwards at a velocity of 32 ft. per second: (a) How high will it rise? (b) What will its average velocity be? (c) What will its final velocity be when it returns to earth?

(44) If a body is projected upwards at a velocity of 64 ft. per second: (a) How long will it continue to ascend? (b) How high will it rise?

Ans. (a), $t=\frac{v}{g}=\frac{64}{32}=2$ sec.

Ans. (b), $h=\frac{1}{2}\,gt^2=16\times4=64$ ft.

(45) A stream is projected upwards with a nozzle velocity of 86 ft. per second: (a) How long will it continue to rise? (b) How high will it rise?

Ans. (a), $t=\frac{v}{g}=\frac{86}{32}=2.65$ sec.

Ans. (b), $h=\frac{1}{2}\,gt^2=16\times7.2=115$ ft.

(46) A body is projected upwards at a velocity of 1,000 ft. per second: (a) How long will it continue to rise? (b) How high will it ascend?

Ans. (a) 31 sec.

Ans. (b) 15,376 ft.

(47) As the theoretical value of g is 32.16, those answers are only approximately correct.

(48) With a flow at the rate of 250 gallons per minute through a 1¼ in. nozzle, what is the velocity of the stream?

(49) A stream is discharged at a velocity of 100 ft. per second: What is the rate of flow through a 1½ in. nozzle?

(50) What height of a column of water will register a pressure of 100 lbs. per square inch?

(51) What is the velocity of a freely falling body after it has fallen from a height of 231 ft.?

Ans. $V=\sqrt{2gh}=\sqrt{64\times231}=121.6$ ft. per sec.

(52) What is the velocity of flow under a head of 231 ft.?

(53) What is the velocity of flow under a pressure of 90 lbs. per sq. in.?

(54) A stream is discharged at an agle of 45 degrees, under a pressure of 50 lbs. per square inch: (a) How high will it rise? (b) What horizontal distance will it have traversed when it reaches the point of maximum altitude?

Ans. (b) Velocity of flow 86 ft. per second. Horizontal velocity $86-\frac{86}{4}$ or 64.5 ft.

$t=\frac{v}{g}=\frac{64.5}{32}=2$ sec. That is, the horizontal velocity is 64.5 ft. per sec. and the time of flight 2 seconds. $64.5\times2=129$ ft.

Ans. (a) The maximum vertical velocity is 64 ft. per second and the minimum zero, therefore the average is 32 ft. per second and the altitude reached 64 ft.

(55) A stream is discharged under a pressure of 75 lbs. per square inch and at an angle of 45 degrees: (a) How high will it rise? (b) What is the horizontal distance to the point where the stream reaches its maximum altitude?

(56) Why does the actual range of a stream dif-

fer from the theoretical range more than the actual range of a projectile differs from the theoretical range?

(57) Discuss the forces that determine the distance a stream traverses before its stream form becomes broken up.

(58) Discuss the forces and the common fire service conditions that determine the distance to which a stream may be considered as an effective fire stream.

(59) A pressure of 200 lbs. is maintained upon a hydrant, 800 ft. of 3 inch hose in line with a 1½ inch nozzle. (a) What pressure is there on the nozzle? (b) What is the rate of flow? (c) What is the friction loss per 100 ft. of hose? The information given in this question is not sufficient to enable us to compute directly from stated facts. But by a series of approximations we may find data sufficient to enable us to proceed. It is apparent that the nozzle pressure must be more than 0 and less than 200 lbs., and any pressure between those points will serve for the first approximation. (Wherever a problem or part of a problem involves an approximation the closer to the facts the first approximation is the more concise the work of solution will be.) In this case assume a nozzle pressure of 64 lbs. per sq. in. With a nozzle pressure of 64 lbs. the volume of flow will be $1\frac{1}{2}^2 \times \sqrt{64} \times 29.7$ or 535 gallons. With a flow of 535 gallons per minute in 3 inch hose the velocity flow is $\dfrac{535 \times 2.7}{60}$ or approximately 24 ft.

per second, hence the value of V, in the formula $F=\frac{V}{D}+\left(\frac{\frac{1}{2}V}{D}\right)^2$, is 24, and the formula may be written $F=\frac{24}{3}+\left(\frac{12}{3}\right)^2=24$, showing that in order to maintain a nozzle pressure of 64 lbs. per square inch on a 1½ in. nozzle supplied through a single line of 3 in. hose will entail a friction loss of 24 lbs. per 100 ft. As there are 800 ft. in the line in question the total friction loss would be 24×8 or 192 lbs., showing the first approximation to be about 28 per cent too high, but 28 per cent of 64 is 18.5, and 64—18.5=45.5, showing that for the conditions stated that a nozzle pressure of 45 lbs. would be maintained.

Ans. (a) 45 lbs.
Ans. (b) 445 gal.
Ans. (c) 17.5 lbs.

Except where great accuracy is required the length of the different size hose lines that will contain one gallon may be considered as 4 ft. for 2½ inch line, 2.7 ft. for 3 inch line, and 2 ft. for 3½ inch line.

(60) Two lines of 2½ inch hose with 500 ft. in each are siamezed and 200 ft. of 3 inch hose stretched from the siamese. What size nozzle should be used: (a) If stream were operated in the front entrance to a store 50 ft. wide and 200 ft. deep, to keep a cellar fire from coming through floor. (b) If stream was operated across a 50 ft. street from a fire escape on the 6th floor, the fire being on the 8th floor of a building 100 ft. by 100 ft? (c) If stream

was directed against an extensive lumber yard fire? (d) What pressure would it be necessary to maintain on engine in each case in order to furnish a good working stream? (e) Under what fire conditions would it be desirable to use a larger nozzle than in (a), (b), (c)? A smaller nozzle than in (a), (b), (c)? (f) Show the relative friction loss before and after reaching the siamese.

(61) A single line of $3\frac{1}{2}$ inch hose 600 ft. long is stretched from a fire-boat and a 3-way connection put on, how many $2\frac{1}{2}$ inch lines should be stretched from the 3-way? (a) To combat an extensive fire in a 4 story 100x100 ft. turning mill, streams to be used from the outside? (b) To operate against a fire spreading in a frame building section? (c) To operate against an extensive fire in a tenement house located between other tenement houses? (d) What size and what kind of nozzles should be used at fires such as are stated in (a), (b), (c)? Give reasons. (e) What supply pressure should be used in each of those cases? Why?

(62) What pressure would it be necessary to maintain upon the pumps of a fire-boat in order to give a pressure of 50 lbs. on the nozzle of a water tower, the nozzle being 2 in. in diameter and operated at a height of 70 ft. above the level of the fire boat's pumps, the boat being connected to the water tower by one 500 ft. line of $3\frac{1}{2}$ in. hose?

Ans. Flow 840 gal. per minute.
Velocity of flow 28 ft. per second.
Friction 24 lbs. per 100 ft.
Friction in line 120 lbs.
Friction in tower 20 lbs.
Allowed for elevation 31 lbs.

Nozzle pressure 50 lbs.
Total 200 lbs.

(63) One 3 in. and one $3\frac{1}{2}$ line, each 1,000 ft. long, connects a water tower to a fire-boat. There is a 2 inch nozzle on the tower which is operated at a height of 70 ft. above the level of the fire-boat's pumps: (a) What would the pressure on the nozzle be if there was a pressure of 220 lbs. on the pumps? (b) What would the rate of flow be in each line? (c) If the tube of the water tower was 5 inches in diameter, what would the velocity of flow in the tube be? (d) What would the velocity at the nozzle be?

(64) What percentage of the fire-boat's capacity would be expended in supplying such a stream, provided the capacity of the boat was 8,000 gal. per minute against a pressure of 125 lbs? (a) If the boat were equipped with centrifugal pumps? (b) If the boat were equipped with reciprocating pumps?

(65) With 150 lbs. on an engine, and 300 ft. of $1\frac{1}{2}$ inch hose in line, what pressure would there be on: (a) A 1 inch nozzle? (b) A $\frac{3}{4}$ inch nozzle? (c) A $\frac{1}{2}$ inch tip?

(66) In a section of a city 2 miles from the nearest fire-boat and $\frac{1}{2}$ mile from the dock at which the fire-boat may make a landing, there are in course of construction, or newly completed, some 200 frame resident buildings. These buildings are grouped somewhat closely and the ground for blocks around is strewn with piles of lumber, shingles, window frames, etc., etc. The water supply of this section consists of one 6 inch main connected to a reservoir 2 miles distant and about 80 ft. higher than the ground level of the fire section.

Upon arriving at the fire the officer in command finds that he has available for service one combination gasoline pumping engine with a capacity of 700 gallons per minute, one steam fire engine with a capacity of 500 gallons per minute and one H. & L. company. The fire was discovered early on a summer morning and before the fire department got into operation one building and a large pile of window frames located nearby were completely involved, while the building to leeward was seriously, and the one to windward slightly, involved. What disposition should be made of the forces, particularly with respect to utilizing to the best advantage the supply of water available?

(67) At a spreading lumber yard fire there is a shortage of pumping apparatus. There is a pressure of 40 lbs. on the hydrants. Under those circumstances, how many lines should be used on a gasoline pumping engine having a maximum capacity of 700 gal. per minute?

(68) The deck pipe of a wagon is placed 20 ft. from the building line, and a stream from this wagon is directed in a window the bottom of which is 20 ft. higher than the nozzle of the deck pipe: (a) What is the length of the stream to the point where it enters the window? (b) What is the length of the stream to the point where it strikes the ceiling, provided the ceiling is 30 ft. higher than the nozzle of the deck pipe?

(69) The 13th floor of a 16 story 100 ft. by 100 ft. factory building located at the northeast corner of 6th and X streets is completely involved, and fire is threatening to extend by front windows to floor above. To prevent this, lines are taken to the

roof of a 10 story structure located on the southwest corner of 6th and X streets; 6th street is 50 and X street 70 ft. wide. What would the length of the stream that would cover the 6th street front to the level of the 14th floor be?

(70) Provided a stream from the position stated in the last question was directed in a window 25 ft. from the corner on the X street side: How long would the stream be in order to reach the ceiling of the 13th floor provided such ceiling were 40 ft. higher than the position from which the streams were operated?

PREFACE TO PART III

Subjects such as mechanics and hydraulics deserve a place of especial prominence in the curriculum of firemen, for a knowledge of them may reasonably be expected to amplify the capabilities of officers for the direction of operations. These subjects consist of facts with which the officer must become familiar, whether he acquires the knowledge scientifically and before entering upon the discharge of his duties as an officer, or by the slow and uncertain process of personal experience, as without such knowledge a fire officer's skill, as an extinguisher of fire, would in no manner excel that of a layman. But suitable to a fire curriculum as those subjects are they do not apply to it with such pointed significance as do combustion, heat, diffusion, radiation and the absorption of radiant energy. The subjects last mentioned will, undoubtedly, furnish the major portion of the study matter that will engage the attention of the future fire officer.

There are some subjects of which persons preparing for participation in scientific professions are required to display extensive knowledge, before being permitted to practice in those professions. Among the subjects with which members of engineering professions are required to establish especial familiarity, are applied mathematics and mechanics (using the term mechanics in a broad sense). The important part that mechanics occupies in the education of engineers, the diffusion of heat by convection and the propagation of heat energy by radiation, will finally take in the educational systems that are in process of development in connection with the work of fire control.

Firemen are preeminently fortunate in finding a subject that furnishes material suitable for training the mind along lines demanding close application and necessitating accurate reasoning, while developing habits of thought along the lines of professional employment. But this is not all the advantage, for what a student

learns from this subject he may apply to good advantage in the actual performance of his work. Thus the subject seems to fulfill all the demands of the ideal course of instruction.

Our present knowledge of thermal science is not sufficient to justify an authoritative statement as to the extent that science may prove sufficiently interesting and applicable to fire control to justify exhaustive investigation and research.

It may be said, as the result of experience, that for the amount of effort expended the subject proved more productive of matter applicable to fire-fighting than mechanics, and vastly more so than hydraulics. From the slight knowledge acquired in searching out those features in which the elementary principles of the science are applicable to fire control it seems a subject of inexhaustible scientific interest, every phase of which has a direct bearing on the work of the fire-fighter.

The study of other scientific subjects firemen will share with the members of other professions, and in relation thereto may benefit by the learning developed in other fields, but in thermostatics they shall find little aid except that derived from pure science.

To make clear the variety of ways in which the scientific principles involved in thermostatics apply to the practical work of fire control will require much study, thoughtful consideration and discussion amongst fire officers.

The younger generation of fire officers are especially exhorted to investigate and develop the subject of thermic forces and their effects. For in that subject may be found a branch of science capable, if properly expounded, of furnishing study matter suitable for the development of fire engineering into a leading scientific profession.

PART III

HEAT: RADIATION: COMBUSTION: ETC.

NATURE OF HEAT.—Heat is that form of energy into which all other forms of energy may be converted. It is produced by the agitation of the molecules of which matter is made up.

When the agitation among the molecules of a body is increased, the heat of the body is increased; when it is lessened, the body is cooled.

TEMPERATURE.—The temperature of a body (mass of matter) is its state considered with reference to its ability to communicate heat to other bodies. When two bodies are brought together, there is a tendency towards an equalization of temperature. If there is an actual transfer of heat between them, the one that has the higher temperature gives the greater amount of heat, but at all temperatures ordinarily encountered some heat energy is transmitted from the colder to the hotter.

The flow of heat from points of high to points of low temperature is frequently likened to the flow of water from points of high to points of low level, and to the flow of electrification from points of high to points of low potential. There is this apparent difference, however, that in the case of heat there is flow in both directions; the change that takes place in the temperature of the bodies being due to the greater flow from the body of higher temperature; while in the cases of water and electrification the flow is in one direction only.

An addition of heat will increase the velocity of molecular motion unless the heat be absorbed in performance of some other kind of work.

When a body receives heat, its temperature rises unless a change takes place in the physical condition of the matter of which the body is composed. When a body

gives up heat, its temperature falls or its physical condition changes.

SENSATIONS ARE AN UNRELIABLE TEST OF TEMPERATURE.—A body feels hot when it is imparting heat to us; it feels cold when it is drawing heat from us.

This may be well illustrated by holding one hand in hot water and the other in cold water, for some time, and then transferring both to water at the temperature of the room. The latter will feel cold to the hand transferred from the hot water and warm to the hand from the cold water.

EXPANSION.—One effect of heating a body is to increase its volume. This increase is the immediate result of the increase in the molecular motions. The amount of the expansion is definitely related to the increase in temperature, and generally proportionate to it.

THE THERMOMETER.—A thermometer is an instrument for measuring temperature. In its most common form it consists of a bulb filled with mercury, connected with a tube of uniform bore. The upper end of the tube being freed of air is hermitically sealed. As mercury boils at about 630 degrees Fahrenheit, thermometers used in connection with experiments in combustion are constructed with porcelain or platinum bulbs and use air in lieu of mercury. Or temperatures are computed from the expansion of metal rods.

GRADUATION OF THE THERMOMETER.—In every thermometer there are two fixed points called respectively the freezing-point and the boiling-point. The former indicates the temperature of melting ice; the latter, the temperature of steam as it escapes from boiling water under atmospheric pressure at sea level. The distance between the fixed points is divided into equal parts according to different arbitrary scales.

The two types generally used in this country are the Fahrenheit and the Centrigrade. The freezing point is marked zero in the latter, and the boiling point 100; while in the former the freezing point is marked 32 and

the boiling point 212. Thus the centigrade is divided into 100 equal parts while the Fahrenheit is divided into 180; so that each degree of centigrade is equivalent to 1.8 degrees Fahrenheit.

ABSOLUTE ZERO OF TEMPERATURE.—The temperature at which the form of molecular motion, that constitutes heat, wholly ceases is called absolute zero. It has so far proved impossible to produce a condition of absolute zero, but theoratical consideration indicates that it is minus 460 degrees Fahrenheit.

PRODUCTION AND TRANSFERENCE OF HEAT, ETC.

SOURCES OF HEAT.—The sun is the great source of heat energy, but other forms of energy may be transformed into heat.

That forms of energy may be transformed into heat may be shown by a great variety of experiments. The most common manner of making the transformation is by friction. But that it may be transformed by other methods may be illustrated by vigorously hammering a piece of wire laid on an anvil or on a stone.

The incandescent particles that fly from a dry grindstone or an emery-wheel in the process of grinding are particles of metal heated white hot by the energy which tore them from the mass of which they formed a part.

Air or other gas becomes highly heated when compressed, as may be observed by capping the end on an ordinary tire pump, and pushing down on, and holding down the plunger a sufficient time to permit the heat to come through the metal.

That liquid may be heated by agitation may be demonstrated by half filling a small thermo bottle with mercury and shaking it vigorously, the temperature being taken before and after shaking.

Heat may also be generated by chemical action.

PRODUCTION OF HEAT.—The ignition of a friction-match illustrates the transformation of mechanical

energy and of chemical action into heat. Such transformations are continually taking place, but unless the attention is called to the subject, they are not recognized.

Combustion is the most familiar illustration of the transformation of chemical action into heat. The heating of saws by use, and of axles and shaft bearings when not properly lubricated, furnish exemplifications of the conversion of mechanical energy into heat.

DIFFUSION OF HEAT.—Heat is transferred from one point to another in two ways, by conduction and by convection.

It is a common error to hold that heat is also transferred by radiation.

A luminous, highly heated, body may communicate periodic disturbances to a medium called ether and heat may result from an absorption of the waves of disturbance (but heat is not transferred by radiation; only energy that is capable of producing heat is thus transferred). So-called radiant heat will be treated of later.

CONDUCTIVITY.—Conductivity is the mode by which heat is transmitted from points of high temperature to points of low temperature by passing from one particle to the next particle, or by which it is transmitted to a distance by raising the temperature of intermediate particles without any sensible motion of them. The conduction of heat is very gradual.

The power of conducting heat is called thermal conductivity.

Experiments show that there is great disparity in the thermal conductivity of different solids. Of the different solids, metals are the best conductors of heat, apparently for the reason that the continuity of particles is greater in metals than in other solids. Of all the solids silver is the best conductor.

By assuming the conductivity of silver to be 100 per cent the conductivity of brass is 24 per cent. And that of iron and steel, the materials in the conductivity of which firemen are especially interested, 12 per cent.

Glass, another structural material of especial inter-

est, from this point of view, has very low conductivity, as have all burnt-clay building materials.

Low conductivity is a property of materials, such as wood, that burn readily.

CONDUCTIVITY OF LIQUIDS AND GASES.—Water has very low thermal conductivity, as have all liquids, except the metal liquid mercury.

The low conductivity of water may be illustrated by weighting down a piece of ice so that it will remain at the bottom of a receptacle which may be nearly filled with water. If some volatile liquid be poured on the surface of the water and ignited, the water can be caused to boil and a great part of it evaporated without melting the ice. A very simple illustration of this property of water may be had by filling a long bottle with boiling water, then standing it in ice water. It will be found after a few minutes that the water in the lower part of the bottle has become quite cold while the temperature of the water in the upper part of the bottle has not been materially affected. The water in the lower section of the bottle seemingly circulates without disturbing that in the upper section. Gases have very low thermal conductivity.

CONVECTION.—This mode of transferring heat is confined to fluids. When a portion of a fluid is heated above the temperature of surrounding portions, it expands and in so doing becomes specifically lighter. Being lighter, per unit of volume, it rises, while the cooler portions of the fluid flow in from the sides and descend from higher points. In this way all the particles of a fluid become heated to practically equal temperature. This mode of transferring heat by the mechanical motion of heated fluids is called convection. It is sometimes, though improperly, referred to as circulation.

Advantage is taken of convection currents, for the promotion of human convenience, in a variety of ways, as to develop steam from water, heat houses, ventilate houses and mines, provide draft in chimneys, etc.

EFFECTS OF HEAT

EXPANSION. The first visible effect which heat has upon a body is to cause it to expand. Practically all solids expand when heated and contract when cooled. The amount of expansion varies with the increase of the temperature and the nature of the substance.

EXPANSION OF FLUIDS.—Liquids and gases expand when heated, and contract when cooled, the amount of expansion varying with the increase of temperature. The rate of expansion is substantially the same for all gases, and is much greater than it is for solids or for liquids. In the case of liquids, the amount of expansion varies with the nature of the substance.

ENERGY OF EXPANSION.—The energy of expansion of solids, particularly metals, is very great and is utilized in many industrial applications. The peculiar interest which the energy so produced has for firemen consists in the danger of heated metal members forcing out walls, or buckling, when heated, and in the latter case being pulled away from their supports when suddenly cooled, as they are when swept by streams of water.

Substances that crystallize on cooling, expand as they approach the temperature of solidification. As a result, a given quantity of matter occupies more space when it has a crystalline structure than it does when in a liquid form. Ice is the best as well as the most common example of such a substance.

COEFFICIENT OF EXPANSION.—The elongation, per unit of length, for each degree that the temperature is raised above zero, is called the coefficient of linear expansion. Similarly, the increase in volume, per unit of volume, for a change of one degree of temperature, is called the coefficient of cubical expansion. It is determined by dividing the increment of volume by the original volume. It may be taken as three times the coefficient of linear expansion.

For solids, the coefficient is nearly constant for different temperatures. For liquids, the coefficient is more

variable. Water exhibits the most remarkable variation from regularity. As water is heated from 32 to 39 degrees Fahrenheit it contracts slightly, so that 39 F. is the temperature at which water has maximum density. Were it not for this peculiarity, for which no reasonable explanation has yet been offered, water would freeze from the bottom upward, which would render the major portion if not the whole earth uninhabitable.

As the temperature of water is raised above 39 degrees the water expands, slightly at first, but more rapidly as it approaches the boiling point. For gases under constant pressure the coefficient of expansion is nearly constant, with a coefficient of $\frac{1}{479}$ or .00209.

LIQUEFACTION.—The liquefaction of a solid is effected by fusion or by solution. In either case heat is required to overcome the forces of cohesion and disappears in the process. In some cases the absorption of heat involved in the liquefaction is disguised by the evolution of heat due to chemical action between the substances used.

An illustration of this is seen in the action of freezing-mixtures.

Where salt and snow or pounded ice are mixed the reduction of the temperature is due to heat being absorbed in the process of solution.

SOLIDIFICATION.—When a liquid changes to a solid, the energy that was employed in maintaining the characteristic freedom of molecular motion against the force of cohesion is released and appears as heat. The amount of heat that reappears during solidification is the same as that which disappears during liquefaction.

LAWS OF FUSION.—It has been found by experiment that the following statements are true:—

(1) A solid begins to melt at a certain temperature that is invariable for a given substance under a constant pressure. This temperature is called the melting-point

of that substance. In cooling, such liquids solidify at the melting-point.

(2) The temperature of a melting solid or of a solidifying liquid remains at the melting-point until the change of condition is complete.

(3) Substances such as ice that contract on melting, have their melting-points lowered by pressure, and vice versa.

While it is possible to reduce the temperature of a liquid below its melting-point without solidification, yet when its solidification does begin, its temperature quickly rises to the melting-point.

VAPORIZATION.—Vaporization is the process of converting a substance, especially a liquid, into a vapor. This change of condition may be effected by the application of heat, or by the diminution of pressure, or by both. When it takes places slowly and quietly, the process is called evaporation. When it takes place so rapidly that the liquid mass is visibly agitated by the formation of vapor bubbles within it, the process is called ebullition. The heat that produces the change of condition disappears in the progress.

CONDENSATION.—The liquefaction of gases and vapors is affected by the withdrawal of heat or by an increase of pressure, or both. In either case, the energy that was employed in maintaining the aeriform condition is released and appears as heat. The amount of heat that reappears during liquefaction is the same as that which disappears during vaporization.

LAWS OF EVAPORATION. — Experiments show that the rapidity of evaporation:—

(1) Increases with a rise of temperature.

(2) Increases with an increase of the free surface of the liquid.

(3) Increases as the atmospheric or other pressure upon the surface of the liquid decreases, it being very rapid in a vacuum.

(4) Increases with the rapidity of change of the atmosphere in contact with the liquid.

(5) Decreases with an increase of the vapor of the same substance in the atmosphere in contact with the liquid.

To such an extent does the pressure on the surface of a liquid affect evaporation that water may be frozen by its own evaporation under very low pressure.

By evaporating liquefied hydrogen a temperature of — 405 degrees Fahrenheit has been obtained. That is a temperature only 74 degrees removed from the absolute zero of science has been reached in this manner.

DEW-POINT.—A space is said to be in a state of saturation with respect to a vapor when it contains as much of that vapor as it can hold at that temperature. The vapor then has the maximum elastic pressure for that temperature. The quantity of vapor required for saturation increases rapidly with the increase of temperature. When a body of moist air is cooled, the point of saturation is gradually approached; when it is reached, any further cooling causes a condensation of the vapor to dew, fog, or cloud, according to circumstances. The temperature at which this condensation occurs is called the dew-point.

The ratio between the amount of watery vapor present in the air and the quantity that is required for saturation at the temperature of observation is called the relative humidity. This ratio is generally expressed in percentages, as 75 per cent or 0.75.

LAWS OF EBULLITION.—It has been found by experiment that the following statements are true:—

(1) A liquid begins to boil at a certain temperature that is invariable for the given substance under constant conditions. This temperature is called the boiling-point of the substance. In cooling, such vapors liquefy at the boiling-point.

(2) The temperature of the boiling liquid or of the liquefying vapor remains at the boiling-point until the change from liquid to vapor, or from vapor to liquid, as the case may be, is complete.

(3) An increase in pressure raises the boiling-point, and vice-versa.

(4) The boiling-point is affected by the character of the surface of the vessel containing the liquid. An effect of adhesion.

(5) The solution of a salt in a liquid raises the boiling-point, additional energy being required to overcome the cohesion involved in the solution.

(a) It is possible to heat water above its true boiling-point without ebullition, by confining the steam and thus increasing the pressure, but when the pressure is relieved, the superheated vapor immediately expands and its temperature is reduced. Strictly speaking, the boiling-point is the temperature at which the elastic force of the vapor is equal to the pressure of the atmosphere.

(b) The temperature of the water in a steam-boiler is higher than 212 degrees Fahrenheit whenever the pressure, recorded on the steam gauge, is greater than one atmosphere. At a pressure of 150 lbs. the temperature within the boiler is more than 320 degrees Fahrenheit.

(c) A drop of water on a smooth metal surface at a high temperature may rest upon a cushion of its own vapor, without coming in contact with the metal. A liquid in this spheroidal state is at a temperature below the boiling-point. When the metal cools so that the vapor pressure will not support the globule of water, the liquid comes into contact with the metal surface, and is converted into steam with great rapidity. Many boiler explosions are due to such causes.

(d) Whenever the boiling-point of a substance is lower than its melting-point, the substance vaporizes directly without previous liquefaction. This change is called sublimation.

The pressure at which the melting-point and the fusion-point of any substance coincides is called the fusion-point pressure. If the fusion-point pressure of a solid substance is greater than the atmospheric pressure, it will sublime when heated unless the pressure upon it is increased. The importance to firemen generally of the heat at which liquids will vaporize, and solids sublime, and the pressures necessary to prevent them doing so, is not sufficient to justify a lengthened discussion in a work of this character. It may be noted, however, that

carbon dioxide sublimes under any pressure less than 45 lbs. per square inch above zero pressure.

It may be suggested that officers serving in districts in which large chemical factories, or warehouses in which chemicals are stored, are located, familiarize themselves with the temperatures at which chemical liquids vaporize, and chemical solids sublime. Where large quantities of chemical vapors or sublimates permeate air, it is injurious, and may be dangerous, to breathe such air for a prolonged period.

DISTILLATION.—Distillation is the application of volatilization and subsequent condensation. Among the various purposes for which the process is employed is that of extracting the essential principle of a substance from the liquid in which it has been macerated.

FRACTIONAL DISTILLATION.—Fractional distillation is the process of separating liquids that have different boiling-points. The mixture is heated in a retort that allows constant observation of the temperature, and the distillates obtained between certain temperatures are collected separately. The most volatile constituent of the mixture will be found chiefly in the "fractions" first collected. By redistillation of the first fraction, the more volatile liquid may be obtained in comparative or absolute purity.

MEASUREMENT OF HEAT

CALORIMETRY.—Calorimetry is the process of measuring the amount of heat that a body absorbs or gives out in passing through a change of temperature or of physical condition.

THERMAL UNIT.—A thermal unit, or a heat unit, is the amount of heat required to raise the temperature of unit mass of water one degree. The unit most commonly used in scientific works is the quantity of heat required to raise the temperature of one gram of water from 0 to 1 degree Centigrade. This water-gram-degree unit is called a therm, or a small calory. A large calory is the quantity of heat required to raise the temperature

of one kilogram of water one degree centigrade. The establishment of a thermal unit is a purely arbitrary matter, and the amount of heat required to raise any stated volume of water any number of degrees may be prescribed as the thermal unit of any particular profession. The thermal unit used by steam engineers, in this country, is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit. As the purpose of the thermal unit is primarily to show the relations between the relative quantities of latent and sensible heat in different substances, and in different forms of the same substances, hence any recognized thermal unit will serve our present purpose.

LATENT HEAT.—In considering conditions of matter, we have spoken of the disappearance and reappearance of heat. When heat thus disappears, molecular kinetic energy is transformed into potential form; when it reappears, the reverse transformation takes place. Because this molecular kinetic energy affects temperature it is called sensible heat. Because this molecular potential energy does not affect temperature, it is called latent heat.

Where heat is applied to any substance, so much of it as increases the rapidity of molecular motions is kinetic and appears as sensible heat. So much of it as is used to oppose cohesion, and to overcome pressure, disappears as latent heat. In other words, that portion of the heat that can be measured by a thermometer, is sensible heat, and is in the form of kinetic energy. While the portion of the heat that goes to change the condition of the matter (as from water to steam) or that may be recorded on a pressure gage is latent heat, and while in this form constitutes potential energy.

When ether evaporates, the potential energy needed to establish the aeriform condition is obtained by the transformation of kinetic energy and at the expense thereof; hence the disappearance of sensible heat and the fall of temperature. When steam is condensed, the potential energy that is no longer required to maintain the aeriform condition is transformed into kinetic energy, hence the increase of sensible heat.

OBJECTIONS TO THE USE OF THE TERMS "SENSIBLE" AND "LATENT".—The objection to the use of the terms "sensible" and "latent," on the ground that they are reminiscences of the exploded theory that heat was a kind of matter, does not appear to be well taken as these words convey to the mind a more accurate picture of what actually takes place than perhaps any words that could be substituted for them. Heat is said to be in sensible form when its presence can be detected by the sense of touch. Heat is said to be latent when its presence is assured but cannot be detected by touch.

LATENT HEAT OF FUSION.—The latent heat of fusion of a substance is the quantity of heat that is required to melt one gram of the substance without raising its temperature, *i. e.*, the quantity of heat that is expended in promoting the molecular activity involved in the change from a solid to a liquid condition.

The latent heat of fusion of ice is about eighty calories. That is, the heat required to melt any weight of ice would warm 80 times that weight of water 1.8 degrees Fahrenheit, or an equal weight of water 144 degrees Fahrenheit, provided there was no change of physical condition.

LATENT HEAT OF VAPORIZATION.—The latent heat of vaporization of a substance is the quantity of heat that is required to vaporize one gram of that substance without raising its temperature. The latent heat of vaporization of water is about 537 calories. That is, the heat required to vaporize any weight of water would warm 537 times that weight of water one degree centigrade, or "any" times that weight of water $\frac{537}{\text{any}}$ degrees centigrade, provided no part of the water is converted into steam during the process.

SPECIFIC HEAT.—The specific heat of a substance is the ratio between the amount of heat required to raise the temperature of any weight of that substance one

degree, and the amount of heat required to raise the temperature of the same weight of water one degree. It indicates the number of calories absorbed or omitted by one gram of that substance while undergoing a change of one degree of temperature.

FORCE OF COHESION.—The force of cohesion differs considerably for different substances. Consequently, when heat is added, the part thereof that is employed against cohesion in giving new positions to the molecules, and that is thus transformed from kinetic to potential energy, or in other words, from sensible to latent heat, is different in different substances.

The specific heat of water is higher than that of any other substance except hydrogen, being 9 times as great as that of iron and 30 times as great as that of lead.

It is the high specific heat of water, the comparatively low temperature at which it vaporizes, and the enormous amount of heat absorbed in vaporization, coupled with its adaptability to being thrown a considerable distance, that renders water the most efficient of all substances for extinguishing extensive or very hot fires.

THERMAL CAPACITY.—The thermal capacity of a body is the number of heat units required to raise its temperature one degree. It is the product obtained by multiplying the mass by the specific heat, and has direct reference to the amount of heat a body absorbs or gives out in passing through a given range of temperature.

RELATION BETWEEN HEAT AND WORK

CORRELATION OF HEAT AND MECHANICAL ENERGY.—When heat is produced, some other kind of energy disappears, and when heat disappears some other kind of energy is produced. The most important of these transformations are those between heat and mechanical energy. It is possible to convert the total of mechanical energy into heat, but so far it has been found impossible to bring about a total conversion of heat into mechanical energy.

Where heat is converted into mechanical energy for the operation of machinery only a comparatively small amount of the total energy of the fuel consumed becomes available for the performance of work.

The Mechanical Equivalent of Heat signifies the numerical relation between work-units and equivalent heat-units.

The quantity of heat that will raise the temperature of one pound of water one degree Fahrenheit is equivalent to 778 foot-pounds. A foot-pound represents the work done in raising one pound one foot against the force of gravity.

From this it may be computed that the amount of heat energy expended in changing one pound of matter from water at 212 degrees Fahrenheit to steam at the same temperature is equivalent to the amount of mechanical energy necessary to raise 208 tons a height of one foot against the force of gravity, or one ton a height of 208 ft. against the same force.

The enormous magnitude of the heat energy produced by the combustion of fuel is impressively presented in the statement that "when the engines of a great battleship or ocean liner develop an amount of mechanical energy equivalent to 50,000 horse-power per hour the amount of heat energy produced by the combustion of fuel is not less than the equivalent of 500,000 mechanical horse-power."

SCIENTIFIC STUDY OF COMBUSTION. — The great amount of energy engendered by the combustion of fuel, and the tremendous waste involved between such combustion and the performance of mechanical work renders research on the subject one of the most promising of scientific studies, and one that should prove particularly alluring to the student of scientific fire control.

Human experience, in a variety of directions, leads logically to the supposition that knowledge may the acquired from a study of the element of combustion in its useful or controlled form that may be helpful in aiding to a better understanding of how the element, in

its uncontrolled or destructive temper, may be most successfully dealt with.

QUESTION OF EDUCATION.—When the enormous masses of combustible material located in the commercial districts of modern cities are contemplated in connection with the tremendous energy, which, science shows, is propagated by combustion a picture of well-nigh appalling magnitude is presented to the mind. A picture, the very potentialities of which questions the adequacy of the present educational system for the preparation of men capable of dealing successfully, satisfactorily, and at a reasonable expenditure, with the vastly greater masses of such materials that the future may see assembled in such locations.

Great as is the energy propagating properties of combustion, the energy (heat) absorbing capacity of water is more phenomenal still. A fact that further urges the scientific inquiry into the question of efficient and economical fire control. The quantity of water capable of absorbing the heat energy which fires produce is but a very small fraction of the volume actually used at fires.

To bring the quantity of water used at fires materially nearer to that essential for the absorption of the heat produced by combustion is most desirable. For by so doing not only would water damage be rendered less burdensome, but the danger of conflagration might be minimized by the better understanding of the proper use of water that should result from an ably directed inquiry into the matter.

HEAT: ITS DIFFUSION AND ITS EFFECTS

HEAT.—The form of heat that is to be considered under this heading, is that which arises from fire in what may be called its uncontrolled state.

Fire may be said to be in an uncontrolled state where the subject matter of combustion rests upon, or is in contact with a considerable amount of combustible material. Or where the heat generated by combustion is,

or may become diffused so as to come into contact with combustible material in considerable amounts.

Wherever contrivances, such as stoves, furnaces, etc., are provided for the combustion of fuel the parts are so arranged that only such combustible matter as is placed in the receptacle can come into contact with the flaming mass, while channels of incombustible material are provided for conducting the heated gases in such manner as to prevent its coming into contact with substances of a combustible nature.

Where fires occur in locations unprovided with barriers against its spread, the area that may become involved as well as the rapidity of its extension depends on the celerity with which the energy of combustion may be diffused, by convection or by conduction.

Heat is transferred, and fire may be said to extend, by conduction, as the particles involved are consumed and those adjoining become involved, and when it extends from one space to another, as from floor to floor, or from room to room, by heating metal floor supporting members, or metal partition parts, doors, etc., where it communicates from one compartment of a ship to another by heating the bulkheads that separate the compartments. In all such cases heat diffusion is by conduction.

Heat is transferred, and fire extends, by convection when energy generated by combustion diffuses through the air, and either in the form of flame, or of non-flaming hot gases, comes in contact with material not involved and causes its ignition.

WIND.—Air currents are a factor of great importance in determining the direction and the extent to which uncontrolled fire may spread; and although its general importance has not been regarded as of sufficient moment to secure its mention in discussions on thermal science, yet as it should prove of peculiar interest to firemen, and as the results of the forces exerted by it are indistinguishably intermingled with the forces of convection, it seems advisable to consider the subjects jointly.

VARIETY OF FIRES.—Much scientific knowledge has been obtained from observation of the combustion of fuel in connection with steam boilers, and with engines in which heat energy is converted into mechanical energy. Some of this knowledge is applicable to conditions met with in fire-fighting. But before considering the extent to which such information may be helpful in promoting a better understanding of the problems with which fire-fighters are confronted, it seems advisable to call attention to an inaccurate, if not false, impression that has found acceptance among fire officers.

Reference is here had to the interpretation which the statement that no two fires are alike has too generally received.

The thought it was no doubt intended to convey by the statement that no two fires are alike is that the conditions prevailing at fires are so varied that rules of universal application cannot, as a general thing, be confidently prescribed. The expression conveys a sufficiently clear and definite idea to persons familiar with fires and with the conditions in connection with them, but should not be used in instructions to those who have had little or no experience in directing operations of forces engaged in combating fires.

The prime ground of objection to this and similar expressions is that it and they are conducive of loose reasoning, and impede that close observation and careful investigation, without which, knowledge of a subject cannot be reduced to such exact form that it may be truly termed scientific.

SIMILARITY OF FIRES.—Fires have many features in common.

In order that knowledge on the subject of fire control may be reduced to scientific accuracy it is essential that a clear understanding be had of these particulars that are common to all fires of an uncontrolled nature.

Possessing such knowledge, officers may be able to make intelligent appraisement of the progress fires have made, their present extent, and the further progress it will be impossible to prevent their making.

Following are some of the particulars in which all fires are similar.

(1) They generate heat. This heat is transmitted by conduction and convection.

(2) They spread. First upwards, next before air currents, then horizontally and equally in all directions, and finally downwards.

(3) They consume oxygen and give off minute particles of unconsumed carbon. These particles, diffused by convection currents, constitute smoke and this smoke, coupled with heat thrown off by the fire, and the abscence of oxygen, render it difficult and sometimes impossible to get close to a fire.

(4) They will not burn vigorously when enveloped in smoke or within a tightly closed compartment.

(5) They will, suitable fuel being available, spread rapidly and burn with terrific energy when draft is available and when smoke clears away.

(6) Where they extend beyond the limits of a structure, they will generally, though not always, spread most rapidly before a wind. That they will not always spread before a wind does not imply any difference between fires but between conditions.

(7) They may be extinguished by:—(a) Cooling involved matter below the combustion point; (b) Impregnating the material of combustion with an incombustible liquid; (c) By cutting off supply of oxygen.

There is an apparent exception to the case stated in (7) (b) where vapors arising from liquids, and sublimates from pyroxlin plastics, are involved. The difference in this case is not between fires but between the nature of the materials supporting combustion.

The case just considered furnishes an excellent illustration of how easy it is to confuse a fire proper with things that are but features of its circumstances.

In fact no clear line of demarcation can be drawn between what is part of a fire and what is a circumstance of its surroundings, for what is a part of the latter one moment, belongs to the former the next.

From the foregoing it may be seen that in those par-

ticulars which have to do with the spread, control and extinguishment of fire the methods that are properly applicable at one fire may be used to advantage at every other, provided the extent of fire and the surrounding circumstances are similar.

The course of reasoning here pursued perforce leads to the conclusion that basic principles which apply to all fires may be developed, leaving it to the judgment of individual commanders to vary those principles as may be demanded by the circumstances surrounding the particular fire with which each may have to contend.

The statement of fire-fighting rules demand a separate work, for to state rules without designating exceptions to them, and pointing out conditions under which they should be varied from, might do harm, and could not, in reason, be expected to result in an improvement of the methods now pursued, and prescribing exceptions and modifications would, of necessity, lead to such a discussion of the whole subject of fire-fighting as to bring a work of that character within the scope of the strategy, rather than the science, of the subject.

HOW FIRES STARTING UNDER CERTAIN CIRCUMSTANCES ACT.—Under this heading only a few general conditions will be considered, and only general principles will be dealt with. Remarks here will be limited to fires occurring under conditions frequently encountered, and presenting no exceptional difficulties.

Heat from fire that occurs on the inside of buildings is diffused by conduction and by convection. Diffusion by the former method is never rapid, does not constitute a grave difficulty, and may easily be provided against by an alert officer.

For this reason it is the spread of fire by convection that shall be treated under this heading.

During the progress of a fire on the inside of a building the heated gases escape by the most convenient opening in the roof or ceiling.

In the abscence of an opening in the roof or ceiling these gases occupy the space along the ceiling down to the level of the highest opening, where they will escape,

in such manner as we may imagine the water flowing from an inverted lake.

The upward course which flame and heated gases adopt determines the direction in which they both will spread, provided the requisites of combustion be present in that direction, and a supply of oxygen, to support combustion, be available from any source.

EFFECTS OF AIR CURRENTS UPON THE SPREAD OF FIRE.—The class of fires considered here are those which occur on the inside of buildings, and which owing to their location are shielded from the effects of winds blowing on the outside. The courses of such fires are rarely affected by air currents, and the possible effect of such currents on incipient fires will be disregarded in the consideration which the subject receives here.

It may be said, however, that no storm, be it ever so violent, is sufficient to prevent a fire extending upward, but as such wind may determine the horizontal direction in which a fire will spread, it is frequently a controlling factor in determining the opening by which a fire will go up.

MANNER IN WHICH FIRE SPREADS IS LARGELY DETERMINED BY THE DESIGN OF THE STRUCTURE IN WHICH IT OCCURS.—The direction in, and the rapidity with which, fires spread are largely determined by the design of the structure in which they occur.

When a fire occurs in a confined space such as a floor of a manufacturing building, the doors and windows of which are closed, it (the fire) may burn for a time with considerable vigor. But as a fire can burn vigorously only when supplied with air possessing a large amount of oxygen, and as the oxygen in such a compartment is rapidly consumed such a fire dies down, and smolders burning slowly downward until it burns through a floor, etc., and thus makes way for a supply of oxygen. When this has been accomplished the fire will burn with some vigor, but unless there be an outlet for the smoke above

the point of the fire it cannot burn vigorously or spread rapidly.

When doors or windows are open, into a floor upon which a fire has been burning, the smoke will, owing to the pressure that has been generated by the heat, belch forth from such opening, while cool air will sweep in along the floor, but as the space along the ceiling, down to the level of the opening, is filled with smoke and gases, out of which the oxygen has been consumed, flame cannot spread along the ceiling for want of oxygen to support its combustion. Where many windows are open, into a floor within which great heat has been generated, it may happen that the fire burst forth with such vigor that the flame generated by it will sweep the non-flaming gases from along the ceiling line and thus spread rapidly throughout a floor. It is to counteract the bad effect of this that experienced firemen wet down the stock on floors that are heavily charged with smoke and heat, before entering upon them.

Fires occurring in areas that have no means of ventilation at the top spread with great rapidity when doors and windows are open, as the flame sweeps along the ceiling when ventilation is furnished and smoke is driven out. Such fires are not difficult to confine but often prove stubborn on account of the difficulty in reaching them owing to there being no means of approaching their vicinity other than by entering by way of the openings through which the heat and smoke are passing off.

As it is intended to avoid practical fire-fighting in this work, all that, at the moment, appears necessary to be said on the subject of how such fires should be handled, is that, in theory, it would be well to cut holes in the flooring immediately above such fires, and thus furnish an upward passage for the heated gases. By so doing it would be rendered less difficult to enter involved areas by way of doors and windows.

The class of structures in which prevailing conditions differ most widely from those just considered are buildings in which there are openings in all the floors and also in the roofs. Where a fire occurs on one of the

lower floors of a building of this character, the heated gases will, in the absence of air currents, ascend by the opening nearest the seat of the fire. Immediately, when those gases (usually in the form of smoke) begin to ascend, currents of air, from all other openings to the fire area, are drawn towards the fire. Those air currents, slight at first, gradually develop in volume and velocity, as the necessity for a larger amount of oxygen to support the increased combustion necessitates the presence, at the seat of combustion, of a larger amount of oxygen-laden air.

By the time sufficient flame has developed to involve matter at a considerable distance from the seat of fire, those air currents have acquired sufficient strength to prevent flame extending against them.

Thus it is that the flame is swept toward one opening on a current of air brought into being and developed by the combustion. As the area involved and the intensity of combustion increase the velocity of these air currents develop proportionately, so that fires in structures of the character here considered seldom, or never, ascend by more than one opening.

Open stairways constitute the class of inter-floor openings most frequently encountered, and are generally arranged one above the other, in such manner as to constitute a vertical flue. When flame reaches a flue of this character, it sweeps upward, catching on to such combustible material as projects into, or is located in close proximity to, this flue, and spreads when it reaches a ceiling through which the opening does not penetrate. Lines of open stairs generally extend from the first to the top floor, but do not extend through the roof. Hence it is that fires in buildings having open stairs, spread (or mushroom) on top floors.

When flames, sweeping up an open stairway, first strike an unpierced ceiling they, in the absence of strong air currents, spread equally in all directions. With the development of greater heat a pressure is generated along the ceiling; when any part of the flame or heated gases reach an opening they sweep upward, and henceforth the

direction of flame, from the seat of combustion, is toward the opening up which the flame sweeps, air currents seting in from all other openings.

Where inter-floor openings are not vertically above each other or vertically above the opening in the ceiling of the original fire floor, there is a diminutive mushrooming on each floor, which continues until the flame reaches the opening to the floor above, when the course of the flame is along the shortest route from the openings in the respective floors.

Whether the openings in the several floors are vertically above each other, or whether they are staggered, so to speak, air is swept to the fire from all openings in the fire area other than that up which fire is extending.

From the facts just considered it may reasonably be concluded that a fire in a structure having an interior flue does not spread through the structure with alarming rapidity unless under the influence of forces outside the fire.

STRATEGY IN FIRE-FIGHTING.—Although the primary purpose of this work is to point out how the teachings of science may be utilized to aid in making the work of fire-fighting more comprehensive, yet a few words on the strategy of the subject seem necessary to round out this part of the discussion.

When upon the arrival of a fire department, at a fire in a building of the character just considered, and such building is found to be seriously involved, the proper strategy is to attack such a fire at the lowest floor, and follow it up, subduing it on each floor before attacking it on floors above. Where such a fire has not ventilated through the roof before the department's arrival an opening should be made in the roof immediately above the fire.

One thing that sometimes is, but never should be done, at fires of this character, is to discharge water against the upper parts of the fire before the material on the lower floors is thoroughly wetted.

The objection to this procedure is based upon the following facts:

(1) That a column of flame and hot gases sweep upward with great rapidity. (2) That during the upward sweep the heated particles cling close together, thus exposing a minimum of surface to the resistance which the ascending matter encounters from the surrounding air.

(3) When a column of flame is swept by a stream, or doused with a deluge of water from a broken stream, the compactness of the ascending column is destroyed. As soon as the column of flame is broken the cool air from the sides rush inward and close the path of the flame, ascending from beneath, as effectually as if a hatch had been dropped over the opening. The ready path, of the column of flame, being now shut off, pressure is generated at that point, which pressure, following the line of least resistance, spreads out horizontally (mushrooms) on the floor immediately beneath that upon which the flame column is broken. Where fire spreads as just stated, streams are invariably directed into the floor within which fire is spreading. The upward current of the flame column is again broken and the flame spreads upon the floor beneath, and so on downward, from floor to floor.

The considerations, just treated of, furnish an excellent illustration of how the science of fire control may be advanced by applying to a study of its principles observed in the study of the combustion of fuel in connection with the development of industrial pursuits.

When it was first observed that where a flame column ascending through openings in several floors was raked by a stream, or hit from above, the flame flared back, and spread on the floors beneath, there seemed no adequate and satisfactory explanation for the suddenness and violence with which the flame spread. It was from a study of the combustion of fuel, in the furnaces of steam boilers, operating under forced draft, that knowledge was acquired upon which the theory here set forth is founded.

When the generation of steam under high pressure necessitated the development and maintenance of great heat intensity under steam boilers it was observed that the

highly heated gases swept from the fires with great velocity, and that as a result a large amount of heat was unnecessarily wasted. To prevent this, resort was had to baffle-plates, which were designed to retard the velocity with which the flame and gases of combustion passed from fire boxes into smoke pipes.

Observation shows that the diffusion of flame, upon striking a baffle-plate in the smoke passage of a furnace, is substantially similar to that which takes place when an upshooting column of flame strikes a ceiling, or where a flame column is hit from above, doused, or raked by a stream of water. The only marked difference being that in the latter case (i.e., where a flame-column is hit with water) a flare back, which does not take place in either of the two former cases may be observed. (This back flare is doubtless due to the generation of vapor, the expansion resulting from which, strikes in all directions, being observable only upon the flame side).

The difference in the conditions prevailing where experiments are made in connection with baffle-plates, and those found at destructive fires, is so great that the similarity of the diffusion may go unobserved unless the reasonable results of such varied conditions be understood.

In the case of the baffle-plates the course of the heat currents is not completely altered, but merely broken, to be taken up again as the gases pass, through holes in, or around the edges of the plate.

Where the flame column of a destructive fire is broken and the flame deflected, it (the flame) usually finds additional material by which its progress may be extended. Those facts result in a very marked difference in the conduct of the flame, after the deflection takes place. But it must be observed that those differences appear as a result of conditions encountered after deflection, and are not directly connected with it.

In both cases the immediate results are similar; when the flame strikes or is stricken, its upward course is prevented and it spreads out along lines of least resistance.

What has been observed in relation to fires that sweep up openings vertically above each other may be sum-

marily stated. Where fire starts, upon the lower floor of a building having openings communicating between the floors, flame sweeps up one such opening, while air is drawn in through all other openings either to support the combustion of the material being consumed or of the heated gases arising therefrom. These air currents prevent flame extending to openings through which they enter, and if an opening exists, or is provided at a suitable point in the roof the fire may be attacked at its source, and if followed up with reasonable promptitude may be subdued before it involves large areas on any of the floors above that of its inception. But if streams be discharged against such a fire at its upper floors, before the intensity of the heat at the source of fire is diminished, or before the material upon the lower floors is wetted, such a fire may spread through all floors and destroy a building.

RADIANT ENERGY

ETHER.—Scientists, who have studied the transference of solar energy, are of opinion that all space is filled with an incompressible medium of extreme tenuity and elasticity. This hypothetical medium is called ether. The variety of phenomena for which the ether hypothesis offers the only explanation that modern science can accept is so great that the unproved existence of the ether is confidently accepted.

The rigidity of this hypothetical substance is so slight that all ordinary matter, and masses thereof, readily pass through it. Its structure is assumed to be continuous instead of granular like that of ordinary matter. It is regarded as an incompressible substance pervading all space and penetrating between the molecules of all ordinary matter which are imbedded in it and connected by its means. It has been compared to an impalpable and all-pervading jelly through which the particles of ordinary matter move freely. This is the substance through which is conveyed the energy which is recognized in the form of light. Heat energy is also communicated by its means. The phenomena of electricity and of magnetism is supposed to result from strains to which this medium is subjected and released from, and the local vortices in which it (the ether) is whirled.

RADIANT ENERGY.—Since the ether fills all the space between molecules, it follows that the vibrating molecules of a body must communicate their motion to it. The periodic disturbances thus communicated to the ether are propagated through it in the form of waves that are supposed to be transverse, and with a velocity of about 186,000 miles per second. Conversely, when these ether disturbances reach a body, they may communicate their energy to the molecules of that body, and thus increase the total energy of that body. The transference of energy by means of periodic disturbances in the ether (without regard to the precise nature of

those disturbances) is called radiation. And the energy thus transferred is called radiant energy.

Radiation is accomplished by the execution of two correlative processes, emmission and absorption. By emmission the disturbances are communicated from a luminous body to the ether. By absorption the disturbances of the ether energize the molecules of a mass. To such extent as the molecules of a mass are energized, to that extent the vibrations of the ether are absorbed by the mass.

Any increase in the vibratory molecular energy of a body increases its total radiation. Any increase in the rapidity of those molecular vibrations correspondingly increases the number of ether disturbances in a unit of time (i.e., increases the wave frequency). There is, therefore, an evident analogy between the phenomena of radiation and those of sound.

The energy of radiation is measured by totally absorbing it and determining the total heating effect produced in the process. Lampblack is the most efficient substance known for absorbing radiant energy.

Incident Radiation may be transmitted, reflected or absorbed by a body upon which it falls. When a body absorbs radiant energy, it is heated thereby.

Radiant Energy is recognized by its phenomena, which are generally classified as luminous, thermal, and chemical.

Not even in theory can a limit be assigned to the length of ether undulations. Some of these waves are competent to excite the optic nerve and produce vision; some are not. The variety of effects should not be permitted to obscure the identity of the cause. All ether vibrations are of similar nature.

Ether waves of any length, so far observed, may be absorbed and when they are absorbed, by any body, the total heat energy of that body is increased.

Disturbances that produce light are limited to undulations having wave length variations of not more than one actave, while the total range of wave lengths already noted are more than seven octaves.

From the two facts just considered it may be sur-

mised that but a small portion of the energy transmitted through the ether passes in the form of waves of a length that produce light.

It is suggested, however, that the disturbances projected into the ether by a body, while in a uniformly luminous state, are, as are sound waves issuing from a source of uniform resonance, of equal length.

If this hypothesis be correct a great part of the total energy radiated is communicated by waves of light producing length.

Most of the properties and phenomena of radiant energy, including those that produce heat, are most conveniently studied by luminous effects. Hence when studying the effect of radiation the subject is pursued largely through the lighting effect.

STUDY OF RADIANT ENERGY BY ITS LUMINOUS EFFECTS.—Light. The portion of radiant enenrgy that is capable of producing the effect of vision constitutes light.

VISIBLE BODIES.—Bodies are visible because of the light that they send to the eye of the observer. This is true whether the body shines by its own or another's light, i.e., whether it is self-luminous like the sun or illuminated like the moon.

Although light makes bodies visible it is itself invisible. The illumination of the path of a sunbeam entering a darkened room is due to the reflection of light by the dust particles floating in the air. When a sunbeam is sent through dustless air, its path is invisible.

Radiant energy is propagated along straight lines when the medium through which it is propagated is homogeneous, i.e., when it has a uniform composition and density.

Ability to take sight depends upon this fact, for we see objects by the light that they send to the eye. A small beam of light that enters a darkened room illuminates a straight path.

TRANSPARENCY.—According to the freedom with which they transmit light, bodies are classified as trans-

parent, translucent, and opaque. Transparent bodies such as glass, transmit light so freely that objects may be distinctly seen through them. Translucent bodies such as oiled paper, transmit light so imperfectly that objects seen through them appear indistinct. Opaque bodies cut off the light entirely, and prevent bodies being seen through them.

When light falls upon a mass of small particles or thin films of substances that are usually transparent, as finely-powdered glass or ice, or froth, or foam, or cloud, or spray, most of the light is reflected. What passes through one particle or film is reflected from another. Such masses are brilliantly white in sunlight. But as the light is reflected and not transmitted, such masses are opaque.

VELOCITY OF RADIANT ENERGY.—The velocity of light is about 186,000 miles per second. Whether this is the velocity of all ether waves has not been determined.

The manner in which the velocity of light is measured is in itself interesting, and seems worthy of being stated here, as it furnishes a very simple illustration of how data is obtained upon which scientific knowledge is founded.

At equal intervals of 42 hrs. 28 min. and 36 sec. the nearest of Jupiter's satellites passes within his shadow and is eclipsed. This eclipse would be seen from the earth at equal intervals if light traveled instantaneously from planet to planet. The earth is about 92,000,000 miles from the sun, and at that distance passes around the sun once in each year. Thus at one period of the year the earth is 184,000,000 miles nearer Jupiter than at another. When the earth was at the point nearest to Jupiter the time of successive eclipses was computed a year in advance. The eclipse observed six months later, when the earth was at the maximum distance from Jupiter, seemed to be 16 min. and 36 sec. behind time, the time which appeared to be lost being gained during the next six months. From this it has been concluded that it requires 16 min. and 36 sec. for light to pass over the diameter of the earth's orbit. It being known that this

distance is about 185,000,000 miles to compute the velocity of light becomes a simple matter. The velocity of light has been measured by other means and results in substantial agreement with that here recorded.

INTENSITY OF RADIATION THAT FALLS UPON A SURFACE.—(1) Varies inversely as the square of the distance between this surface and the source of radiation.

(2) Varies with the angle that the incident radiation makes with the surface, being at a maximum when the surface is perpendicular to the direction of propagation.

(1) May be illustrated by showing that when the distance from an opening, through which light is projected, is doubled the area exposed to the light is increased four times, while the number of rays falling upon the larger surface is identical with that which fell upon the smaller. The energy of ether waves is not diminished by distance, but the number of rays that strike within a given area is diminished to one-fourth if the distance of the object from the propagator be doubled.

(2) May be illustrated by admitting a brilliant light through one opening into an otherwise darkened room, and placing a book in the path of the light in such manner that it (the light) shall fall obliquely upon one side of the cover. If while in this position a line be drawn from the distant edge of the book to the source of light it may be seen that only such rays strike the cover as pass between the line and the near edge of the book. One such experiment during which the book is turned slowly from a position in which the rays strike the cover at right angles, to one in which the rays no longer strike that cover will teach all it is necessary to know on this phase of the subject.

REFLECTION OF RADIANT ENERGY.—Reflection of radiant energy is the sending back, of incident ether waves, by the surface upon which they fall into the medium from which they came. The reflection may be regular or irregular.

The proportion of the incident energy that is reflected increases with the angle of incident and with the degree of polish of the reflecting surface, and varies according to the nature of the reflecting surface.

REGULAR REFLECTION—Regular reflection results from the incidence of radiant energy upon a polished surface. When a beam of light falls upon a mirror, the greater part of it is reflected in a definite direction, depending upon the angle at which the incident rays strike the surface. In the mirror there is formed an image of the object from which the rays come. A perfect mirror would be invisible.

Irregular reflection or diffusion results from the incidence of radiant energy upon an irregular surface. It is the light diffused that makes an object visible to the eye.

LAW OF THE REFLECTION OF RADIANT ENERGY.—The angle of incidence and the angle of reflection are equal, and lie in the same plane.

CONDITIONS ENCOUNTERED IN FIRE-FIGHTING AFFECTED BY RADIATION

RELATIVE RADIATING PROPERTIES OF LUMINOUS AND NON-LUMINOUS BODIES.—As has before been pointed out, there are ether waves that do not produce light. Disturbances of this character are generally denominated, in scientific works as "radiant heat." (The term is not used in this work, as it is misleading, in that it tends to a promotion of the belief that there is such a thing as radiant heat, which there is not). When it becomes necessary to deal with the phenomenon thus described resort will be had to the more accurate, if more cumbersome, method of describing the performance, information relative to which it is sought to convey.

That vibrations in the ether are produced by hot though non-glowing bodies, which vibrations will upon coming into contact with an absorbent body communicate to that body the energy with which they are endowed, may readily be established by any of a variety of experiments, a very simple one being to heat a clay brick until it glows, and after the glow has disappeared to hold the hand immediately beneath it. The heat that comes to the hand from the brick can traverse the space intervening the hand and brick in no other manner than by the propagation of heat energy. For heated air will not descend under conditions such as would be at all likely to prevail where such an experiment was in progress.

That there is great difference in the relative degrees of heat that are derived by radiation from glowing and non-glowing bodies, of equal temperature may be established by simple experiments.

If a section of burnt clay, of equal dimensions and volume with a block of welding iron, be placed in hot fire some time before the iron is inserted, and both are allowed to remain in the fire until the metal is glowing

white hot, the temperature of the clay cannot be less than that of the metal and yet the glowing mass of metal will ignite a sulphur match at a distance at least six times as great as will the section of clay. This indicates that with equal temperatures the radiating power of a glowing mass is at least thirty-six times as great as is that of a non-glowing mass of equal temperature.

The disparity of the heat energy radiating powers of glowing and non-glowing bodies is further borne out by experiment with blue and white flame, for while blue flame may be capable of transmitting far greater heat to a body placed in direct contact with it, so that the heat is communicated by conduction, or placed above it, so that the heat is communicated by convection, its radiating powers is vastly inferior to that of white flame.

From the facts just considered it is reasonable to infer that the danger of fire extending by reason of radiation from any non-glowing body is extremely remote.

NO PART OF THE ENERGY THAT IS IMPARTED TO ETHER IS ABSORBED THEREBY.—It has been fully demonstrated that no part of the energy imparted to ether is absorbed. And this fact furnishes the principal basis for the theory that ether is unlike all ordinary, tangible matter, in that it is not composed of particles but consists of one continuous substance. For, it is contended, if the ether consisted of particles friction would result from the resistance which these particles would offer to vibrations imparted by a glowing body, and heat would result from such friction, which would necessitate an absorption of some of the energy originally imparted.

The most illuminating illustration that can be furnished of the transfer of heat energy, without heating the medium by which the transfer was accomplished, is that which may be based upon the transfer of solar energy to the earth.

Were it not for the disturbances that the glowing mass of the sun excites in the ether surrounding it, not only would life on earth be impossible, but the tempera-

ture of the earth's surface would soon approximate absolute zero.

As before stated the earth is 92 million miles from the sun. If the earth were one million miles from the sun, the heat energy it would receive from that body would be the square of 92, or 8,464 times as great as it now is, and yet the tremendous energy, capable of producing this enormous amount of heat does not raise the temperature of the space intervening the sun and earth one degree above absolute zero. The fact just considered is pointed out by way of emphasis to the statement that no part of the energy communicated to ether is absorbed by that medium.

When pulsating ether encounters masses of ordinary matter, either in the form of gas, liquid or solid, those pulsations are supposed to be impeded by the resistance which they encounter from the molecules of such matter.

Where there is a complete absorption of radiant energy, it is thought that the total energy of radiation is expended in promoting agitation among the molecules of the absorbing matter. The effect on the absorbing body is registered in an increase in temperature.

Some subsances offer but slight resistance to the passage of solar energy, while the surface of other substances absorb the whole of it. The cause for this is not well understood, but the great extent to which it operates may be seen from the tremendous energy which the sun delivers to the surface of a tropical desert, although the vibrations by which the energy is communicated have traversed many miles of dry air, while a thin coating of lampblack, or a thin vein of smoky air, will absorb the whole of the energy, and continue so to do indefinitely.

Since the vibrations that are not reflected from a body, or absorbed by it, must of necessity pass through it, it might reasonably be supposed that the density of a mass (i.e., the close arrangement of the molecules of which the mass is composed) would constitute a controlling factor in determining the resistance which a body might offer to ether undulations. This, however, is not so, for

they (the undulations) pass readily through glass and diamond formation, while being quickly absorbed by smoke. Color seems to be the most important single factor in absorbing waves of light producing lengths, while the power to absorb other disturbances, that do not produce light, does not seem to be influenced by color.

PARTICLES OF CARBON.—Minute particles of carbon given off in the process of combustion play a very important part in that phase of radiation that directly affects the work of fire control. While such particles are suspended in flame they glow with great brilliancy, and apparently constitute the principal cause for the great ether disturbing properties of glowing bodies. When carbon particles pass beyond the flame they instantly become black, and now, in a form called lampblack, furnish the most perfect absorber of radiant energy discovered so far. Particles of carbon arising from combustion, and passing beyond the flame, as here stated, furnish the colorless matter that renders smoke black. Hence radiant energy is quickly absorbed by smoke. From this it may be seen that there is little if any risk of fire extending, by radiation, through a smoke charged atmosphere, and that the danger of fire extending by radiation is limited to the risk that emanates from flame, or other glowing vapor, or glowing mass of a solid body, existing, or coming into being, in proximity of combustible matter, and under circumstances that expose such combustible matter, on at least one side, to such glowing mass, the intervening space being free from smoke or other matter of a nature to absorb radiant energy.

From all of which it may be concluded that the early progress of fires, occurring on the inside of buildings, is not materially accelerated by radiation.

COLD RAYS.—It has been observed that it is essential to the propagation of great heat, by radiation, that the disturbances, that constitute the energy, take place in wave lengths that produce light. Light, however, may be communicated by waves incapable of producing any considerable heat. For while direct radiation, from a glowing body as the sun, or from a flaming torch, is

communicated by disturbances that produce much heat, yet radiation, caused by reflection from a non-glowing body, as the moon, or the surface of water, is communicated by waves that promote vision but little heat.

By lengthening to vision range the vibration-frequency of ether disturbances that are too brief to produce light, illumination has been effected without sensibly increasing the temperature of the body effecting the change in wave frequency.

From all this it should be apparent that the subject of radiation is one requiring the application, not only of close observation, but in an even greater degree, of careful and well balanced reasoning in order that unsound conclusions may be avoided.

RADIATION WHILE FIRE IS CONFINED INSIDE A BUILDING.—It generally happens that where fires occur on the inside of a building, the smoke arising therefrom, is unable to find a free ascent; thus the air within the compartment involved becomes charged with smoke before sufficient heat is generated to enable such a fire to extend by radiation.

There is at least one class of fire that may spread on the inside of a building by radiation. This is the class of fire that, starting on a lower floor, extends upward by a vertical opening, to and through the roof. (Such a fire as was discussed under the heading of Convection.)

There is little doubt but a fire of this character may spread by radiation, although while so spreading, the flame will draw toward the vertical opening up through which the flame first finds a passage.

It is also a reasonable surmise that the extraordinary celerity, with which such a fire spreads when the upward current of the flame and heated gases is broken, is due in no small part to the material exposed to radiation being dried and having its temperature raised close to the ignition point.

This, however, only emphasizes the imprudence of breaking the upward current of heat until the material exposed to the effects of radiation is wet down.

Some question appears to have arisen as to whether

ignition can be caused by radiation, in the absence of any diffusion of heat by conduction or convection, or of the generation of heat by mechanical friction, but that it can has been established beyond reasonable doubt by a variety of incidents.

A few illustrations should be sufficient to establish this fact. Fires have frequently been started by converging the sun's rays upon combustible matter. Fires have been known to extend to the inside of a building through glass windows, there being no openings on the side of the structure which thus became involved, and this even where the structure to which the fire extended, was on the windward side of original fire.

RADIATION AT EXPOSURE FIRES.—When a fire breaks through numerous openings in the front, rear, etc., of a building, or where it occurs in the open, as in frame building or lumber districts, the smoke arising therefrom will, in event of calm weather, ascend vertically. The upward rush of flame and heated gases that takes place in connection with large exposure fires results in a draft that draws air from all sides, rendering it impossible for such a fire to spread horizontally as a result of convection. But the air being clear on all sides, such a fire may extend by radiation, in any direction in which suitable food for combustion may be within range.

Where a fire has developed sufficient radiating power to ignite material, of ordinary combustibility, at a distance of 100 ft., within 15 min. of the time such material became exposed to the heat, it may be said to constitute a serious conflagration hazard unless there be available a fire-fighting force capable of providing one stream for each 50 ft. of exposed front for each floor involved.

The distance has been set at 100 ft. for the reason that it has been observed that unprotected material at that distance will ignite as quickly as will similar material, at a distance one-third less, when protected by glass. This represents the amount of heat necessary to ignite fibers behind glass across an ordinary business street.

A fire does not constitute a serious conflagration hazard

to a city provided with a department of reasonable efficiency, until it has developed or displayed an ability to develop a temperature of 400 degrees (at a distance of 100 ft. in a line perpendicular to a fire at its middle point).

When a temperature of 400 degrees above that of the surrounding atmosphere is developed at a distance of 100 ft. the temperature at a distance of 200 ft. will be $\frac{400}{4}$ or 100 degrees above the atmosphere and this is about the greatest heat into which, without protection, men are capable of advancing a line.

The degree of heat that a fire must attain in order to constitute a conflagration hazard depends to a great extent upon circumstances, many of which will occur to the reader. Amongst those which may not so occur is one of controlling importance. This is the factor of the area of radiating front. The importance of the area of radiating front is due to the fact that the rule, to the effect that the vigor of radiant energy varies as the square of the distance from the radiating body, cannot apply at distances from that body, less than the horizontal dimension of the radiating mass. This is so for the reason that at less distances the heat rays in spreading out cris-cross each other, toward a line, perpendicular to the fire front, at its middle point, making the number of rays within a given area more than one-fourth the number within an equal area, at one-half the distance from the fire.

That the exact temperature at which a fire becomes a conflagration hazard cannot be definitely stated, or reduced to mathematical form, does not diminish the advantages to be derived from a study of it, for excellent mental training may be gained through a study of the most elusive subjects provided they deal with tangible matters, and with performances that are consistent.

It requires a considerable fire to cause ignition by radiation at a distance of 100 ft. But it is frequently

necessary to prevent the ignition of materials much closer to a fire.

The best methods of procedure, where it becomes necessary to guard materials from ignition by radiation, like many other questions of fire-fighting, depends to some extent upon circumstances. This much, however, may be confidently asserted. The best method of using water, when but a limited supply is available, and the purpose it is sought to accomplish is to prevent the spread of fire by radiation, is to keep the threatened material wet. Where it is impracticable to get into a position from which this may be done, the next most effective procedure is to form the most complete water curtain possible between the endangered material and the fire. A considerable quantity of water is necessary to form an effective water curtain, particularly where the curtain is to be formed against an involved building. Where a water curtain is to be used it should if possible be formed against the threatened building, for when used in this manner the reflecting properties of the water become available, while if the water curtain be formed against the fire building the flames will come through and only the water's power of absorption becomes available for preventing the passage of heat and heat energy. Where the distance between the involved and the threatened material is more than 30 ft. it will generally be found better to break streams into spray rather than form a curtain against the involved building. Where streams are used as last stated the spray should be formed as close to the threatened building as practicable, which is equivalent to as distant from the involved building as may be consistent with keeping such spray between the danger and endangered points.

Whenever streams are broken into spray for the purpose of preventing the spread of fire, by radiation, such streams should be discharged to a height not greater than sufficient to furnish a spray shield in the direct path between the flaming mass and endangered material.

The general custom, in such cases, is to discharge streams to their full height. This custom, is doubtless,

an outgrowth of a natural impulse to act vigorously when contending against what appear to be great forces.

As it has been found necessary, in this case, to advise contrary to established custom, and particularly as the custom with which we take the liberty to differ, is an outgrowth of instinctive action, it is deemed advisable to go somewhat fully into the reasons it has been regarded as necessary to question the recognized methods.

It should be understood at the outset that by swishing a nozzle from side to side alternately, either more or less rapidly, a stream may be broken at any desired elevation short of its maximum reach.

The disadvantages of sending a stream, the water of which is to be used as a spray shield, higher than the top of a direct line between a flaming and involved body, are:

(1) Where a stream is thrown so as to reach its maximum height, the water ascends in a column, and as a result accomplishes no direct useful purpose while ascending.

(2) When a stream is broken above the top of a line between the flaming and involved bodies, its descent is accelerated to such an extent that the period it spends within the line of radiation is extremely brief, while the period spent within the line of radiation constitutes one of the prime factors in determining the efficiency of the method here proposed for using water to prevent spread of fire by radiation.

The advantages of breaking a stream before it attains a height exceeding the top of the line of radiation are:

(1) The more rapidly a nozzle is swished, from side to side, the closer to the nozzle the stream is broken. Furthermore, the more rapidly the nozzle is moved the smaller the globules into which the water is broken, hence the greater the surface of fluid exposed. (To break streams, used in this way, into small particles is extremely desirable, for as radiant energy is reflected by water, a small particle is practically as efficient as a large one.)

(2) Where the continuity of a stream is broken close to a nozzle, the water globules are in the path of radia-

tion while ascending as well as while descending. They also move across the space through which radiation is in progress at the minimum velocity at which it is possible to have unsupported water particles move.

The difference in the length of time that particles of water are in the path of radiation, when streams are skilfully operated, and when operated without regard to the principles involved may be shown mathematically.

Assume that the path of radiation has a depth of 16 feet.

Provided a stream be broken so that the highest altitude the particles of water reach is level with the top of the path of radiation, then those particles will be within that path for a period of two seconds, one second in ascending and one in descending. For we know that the first second that a freely falling body, starting from rest, is descending it traverses a distance of 16 ft. and that a free body traverses a like distance during the last second of its ascent.

Where a stream is discharged so that particles attain an altitude of 100 ft. above the top of the path of radiation, they will upon reaching that point be moving at a velocity of 80 ft. per second and will pass across the space through which radiation is in progress in less than one fifth of a second, or less than one-tenth of the time it would take were the stream operated judiciously.

EFFECT OF WATER UPON HEAT AND UPON RADIANT ENERGY.—The different manner in which water affects heat and heat energy should be clearly understood by firemen, so they may be in a position to utilize streams in such manner that the best results may in every instance be obtained.

Men operating on the smoky side of a fire encounter heat. Those operating on the windward, or clear, side encounter, not heat, but heat energy which is transformed into heat upon coming into contact with their clothing, etc. When streams are operated, under the former of these conditions, the water absorbs the heat, or it may be said that there is an exchange of heat between the water and the air, and as a result the temperature of the air is diminished, and to the extent of such

diminution that heat is finally disposed of. While where streams are used under circumstances such as stated in the latter case, the heat is not absorbed, the radiant energy being reflected, that is, its direction of motion is merely changed, the energy still continuing with practically undiminished vigor.

The inability of water to absorb radiant energy accounts for the apparent ineffectiveness of streams discharged against large, glowing, exterior fires, a thing that has been noted by many experienced firemen, but for which no adequate explanation has heretofore been offered. The fact that water reflects but does not absorb radiant energy gives rise to the question of whether streams may be used to better advantage in operating at glowing fires, than they heretofore have been. Neither our present knowledge of the subject, nor the progress so far made toward the comprehensive treatment of fires, seem to justify a discussion of the subject of whether streams might be used to better advantage than by discharging them straight against glowing white fire.

While on this phase of the subject it is deemed well to offer an explanation of another phenomenon, that many firemen have observed, and for which the cause assigned seems utterly inadequate. When a stream is discharged against an extensive white hot fire it presents the appearance of a glistening column until it comes within 20 to 25 ft. of the flame, and at this point the stream disappears completely as if cut off there.

The explanation heretofore offered for the disappearance of the stream has been that it was burned up.

In support of this contention it is pointed out that fires of the character with which we are now dealing generate sufficient heat to burn water.

For the sake of simplifying the discussion, it may be conceded that sufficient heat to burn water may develop at conflagration fires, and that the total heat generated may be sufficient, for a time, to consume all the water deliver against such a fire, yet we are still unable to see how sufficient heat can come in contact with the stream at the point of its disappearance to convert the water into vapor and burn this. While contemplat-

ing the possibility of streams being burned up, we must bear in mind the enormous amount of heat energy necessary to vaporize water, without increasing its sensible temperature, and also the fact that the combustion point of water vapor is more than 2,000 F. degrees higher than the vaporization point of water. When, in addition to all this, the fact that water reflects radiant energy is taken into consideration, we may see how illogical the burning theory is.

Doubtless, what takes place is, when a stream penetrates a glowing mass of the character here considered, to sufficient distance, the stream reflects the radiant energy in such a manner as to render itself invisible.

In this connection it must be remembered that a perfect mirror would be invisible.

There seems to be sufficient evidence to support a contention that water reflects ether disturbances, when propagated in the form of wave lengths, that produce extraordinarily brilliant effects, to such an extent as to render a stream of that fluid invisible under such conditions as may prevail at fires of the character here considered.

The causes of fires spreading, as well as the direction in and vigor with which they do so, being considered, in a general way, the disposition of forces in a manner to most effectively cope with a contingency arising as a result of such spread becomes a proper subject for inquiry.

The disposition that, in reason, seems most likely to prove gratifying consists in assigning the major portion of available forces to positions to leeward, while light operating forces, or forces for observation purposes, as the needs of each particular case may demand, should be assigned to windward and to flank positions.

From this it may be seen that the disposal which science approves is, in this instance, in absolute accord with the methods that have been developed as the result of experience. From all of which it seems reasonable to infer that few radical changes, from present methods, will be likely to result from the application to fire-fighting of knowledge classified as scientific.

If this surmise should prove correct it will be in accord with experiences that have been generally encountered wherever duties, once performed by men possessed of a high degree of technical training, have later devolved upon others favored with more extensive educational advantages. That the latter type of men attain better results is a fact that may be attributed, in as great a degree, to the keener appreciation of relative merits possessed by those of more broadly trained intellects, as to the introdutcion of scientific methods of operation into the work.

To stop a fire spreading before a wind is a much more difficult task than to stop one extending by radiation:

(1) Because the smoke, by obscuring the view makes it impossible to operate streams to the best advantage.

(2) Because the heat may become so intense as to render it impossible to hold positions in the path of an onrushing fire, or sufficiently close to it to enable streams to reach the flaming material. This condition prevails wherever a hot blast fire develops.

(3) Material in the path of convection may become dried and heated at a much greater distance than can be the case where the heating is due to radiation. And, moreover, the heating and drying effect is not limited, as in the latter case, to material facing the flaming mass. i.e., radiant energy does not circle around objects as do heated air or gases.

(4) Burning brands and embers are generally carried to leeward.

(5) Owing to the smoke, fires resulting from brands and embers may attain considerable headway before being detected.

(6) Owing to the obscurity caused by smoke it is difficult to move lines to new positions. The difficulty of effecting a change of position becomes greater during the night, and this is the time during which hot blast fires make greatest progress.

The necessity of abandoning equipment which owing to darkness it was impossible to remove has proven a grave handicap to departments in dealing with hot blast fires.

ADHERENCE TO KNOWLEDGE FOUNDED UPON EXPERIENCE.—While working for the development of more effective methods of fire-fighting, and for the application to the work of that calling of principles which have been established scientifically, in other fields of endeavor, we must not forget even the simplest lesson developed in the school of experience.

In dealing with spreading fires, the lee is the side of greatest danger. Not that a fire will spread more rapidly to lee than to windward (in some cases it will not), but, (1) because it is comparatively easy to check a fire spreading by radiation, and (2) the danger of a fire extending by radiation is short-lived.

Wherever radiation is in progress, with sufficient vigor to produce results such as these in which we are now interested, there is light, and as a result streams can be operated to advantage. This fact, coupled with the circumstance, that a small quantity of water used to wet down threatened stock, to form a water-curtain over exposures through which it is feared ignition may be effected, or to form a spray shield between a glowing mass and endangered material, will suffice to prevent spread by radiation, establishes the contention that there is little danger of a fire spreading by radiation where the services of a fire department is available. This is true even while a fire is at its height, and as soon as the vigor of combustion commences to diminish, the danger of spread to windward is past, as the fire in extending leeward increases the space between the fire and combustible matter on the windward side.

PRACTICE EXERCISES
PART III

(1) What is heat?

(2) What is it that causes heat to exist?

(3) What is light?

(4) How is light produced?

(5) State particulars in which light and heat are produced in a similar manner.

(6) What is combustion?

(7) What is diffusion?

(8) What is meant by the diffustion of heat by: (a) Conduction? (b) Convection?

(9) Is radiation a form of heat diffusion?

(10) How does radiant energy differ from thermal energy?

(11) How does convection differ from circulation?

(12) How does the heat of the sun warm the earth, leaving the intervening space at absolute zero?

(13) How is it that fires frequently extend against the wind?

(14) Why is it that the subject of radiation is studied through its light rather than through its heat producing effects?

(15) Explain the causes for fire spreading to windward.

(16) Describe the conditions that are referred to as the hot blast.

(17) It is a well recognized fact that the closer to a fire the greater the heat. Is there any method of computing the relation between temperature and the proximity to fire?

(18) State a set of circumstances and conditions under which conduction, convection, and radiation all operate at the same time to cause the spread of a fire: (a) In the same direction. (b) In different directions.

(19) By what manner of heat diffusion does fire extend: (a) Through the floor of a fire-proof building?

(b) To windward of fire? (c) To leeward of fire? (d) Upward? (e) Downward?

(20) Discuss the relative temperatures on the lee and windward side of fires, and show circumstances under which the temperature on the windward may be greater than that on the lee.

(21) The temperature of flame at an extensive fire is 2,000 F. and 1,000 F. at a distance of 40 ft.—from the fire. (a) What is the temperature at a distance of 60 ft.? (b) At a distance of 80 ft.? (c) At a distance of 160 ft.?

(22) Explain the underlying causes for the rapid increase in temperature as fire is approached: (a) From the windward. (b) From leeward.

(23) State the general principles involved in the extension of fire, and give in each case an illustration of the operation of the principle.

(24) State the various properties of water that renders it such an efficient agent for the extinguishment of fire?

(25) Combustible matter is found in a great variety of forms. Water is not an efficient medium for extinguishing fire in some of those forms: (a) Name 10 such forms of matter. (b) State in each case the properties water lacks to render it an efficient medium for the extinguishment of fires in such forms of matter.

(26) State the 10 most common causes of fire, and show specifically the precautions that should be taken to prevent fires occurring from each cause so stated.

(27) How may water be used most advantageously to extinguish fire in ordinary matter?

(28) State the 5 most important precautions that should be taken to provide against the spread of fire.

(29) How may water be used most advantageously to prevent the spread of fire in ordinary matter?

(30) Show 5 distinct ways in which water may be used to prevent the spread of fire, from forms of matter in which water will not extinguish fire, to forms of matter in which water will extinguish fire.

(31) What is "The Water-curtain?"

(32) State the various conditions under which "the water-curtain" may be advantageously used.

(33) What is a spray shield?

(34) State various conditions under which a spray shield may be used to advantage.

(35) When streams are used to form a spray shield how high should the streams be thrown?

(36) What effect has a spray of water on the passage of heat when used on the lee side of a fire?

(37) What effect has a spray of water on the passage of heat energy, such as is encountered on the windward side of a fire?

(38) State the various operations that may aid firemen to approach closer to a fire than it is possible to do without the execution of those evolutions.

(39) Describe the proper execution of the operations stated in (38).

(40) What are the most suitable materials for the construction of shields under cover of which firemen may advance closer to a fire than can be done without protection from the direct effects of heat?

(41) When a stream is directed into a glowing mass of flame it disappears at a considerable distance from the flame. Explain the cause of this disappearance.

FRICTION LOSS IN FIRE HOSE.

Based on Tests of Best Quality Rubber-Lined Fire Hose.*

Flow, Gallons per Minute.	Pressure Loss in Each 100 Feet of Hose, Pounds per Sq. Inch				Flow, Gallons per Minute.	Pressure Loss in Each 100 Feet of Hose, Pounds per Sq. Inch		
	2½" Hose.	3" Hose.	3½" Hose.	2 Lines of 2½" Siamesed.		3½" Hose.	3½" Hose.	2 Lines of 2½" Siamesed.
140	5.2	2.0	0.9	1.4	525	23.2	10.5	16.6
160	6.6	2.6	1.2	1.9	550	25.2	11.4	18.1
180	8.3	3.2	1.5	2.3	575	27.5	12.4	19.0
200	10.1	3.9	1.8	2.8	600	29.9	13.4	21.2
220	12.0	4.2	2.1	3.3	625	32.0	14.4	23.0
240	14.1	5.4	2.5	3.9	650	34.5	15.5	24.8
260	16.4	6.3	2.9	4.5	675	37.0	16.6	26.5
280	18.7	7.2	3.3	5.2	700	39.5	17.7	28.3
300	21.2	8.2	3.7	5.9	725	42.3	18.9	30.2
320	23.8	9.3	4.2	6.6	750	45.0	20.1	32.2
340	26.9	10.5	4.7	7.4	775	47.8	21.4	34.2
360	30.0	11.5	5.2	8.3	800	50.5	22.7	36.2
380	33.0	12.8	5.8	9.2	825	53.5	24.0	38.4
400	36.2	14.1	6.3	10.1	850	56.5	25.4	40.7
425	40.8	15.7	7.0	11.3	875	59.7	26.8	43.1
450	45.2	17.5	7.9	12.5	900	63.0	28.2	45.2
475	50.0	19.3	8.7	13.8	1,000	76.5	34.3	55.0
500	55.0	21.2	9.5	15.2	1,100	91.5	41.0	65.5

The above table is a reproduction of page 27 of a pamphlet upon hydraulics issued in 1915 by the National Board of Fire Underwriters, and furnished to fire officers. These tables are entered here so that students may readily compare them with their computed findings. The writer assumes no responsibility for their accuracy, and the formula given in this work can easily be altered should it prove that the actual friction loss is greater than that here shown, a supposition that seems to be borne out by the fact that the friction in new iron pipe of the same size as hose lines is approximately twice as great for equal velocity of flow.